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Columbia Basin Project

WITH APPENDICES

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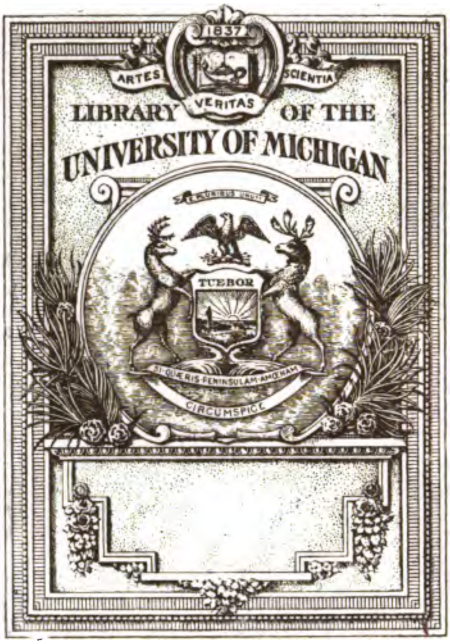

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The Columbia Basin Irrigation Project

Washington (State)

A REPORT BY

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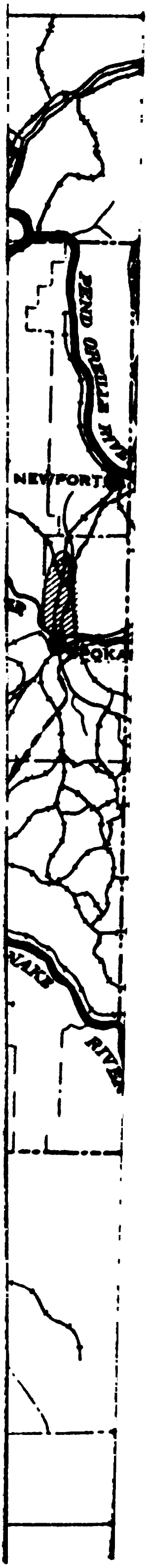
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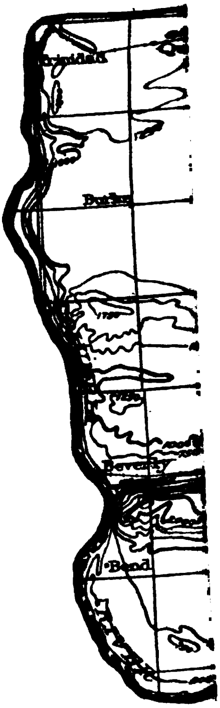

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CHAPTER I.

GENERAL INTRODUCTION.

(1) *Foreword.* The Columbia Basin Irrigation Project proposes to irrigate 1,753,000 acres of land, using a gravity supply of water from the Pend Oreille River.* This source is ample to meet any irrigation demand. The average requirement of the project for water is equivalent to thirty-three inches of rain. Depending upon the size of individual ownership, from 20,000 to 40,000 farms will be developed. The cost of the completed project is estimated at $171.40 per acre.

The four major problems presented by the project are:

(1) Quality of lands under project.
(2) Will competent and sufficiently numerous persons settle on the land to insure successful development?
(3) Can the lands be adequately watered?
(4) Can the cost of reclamation be provided?

(2) *General.* The Columbia Basin is in southeastern Washington, easily accessible to cities and the Pacific Coast. A network of transcontinental and local railroads and a well-developed system of state highways afford ample means of transportation to the markets of the nation and the world.

The crops which will predominate under irrigation are such as find a ready and wide market. The application of water to this great arid area will yield agricultural, horticultural, dairy and livestock products which will add greatly to the wealth of the state and nation.

In past ages the Columbia Basin was a vast inland lake, the floor of which became covered with a deep, rich and abundant soil. As the waters of this great lake receded to the Pacific it left a heritage of rich but arid land for agricultural development, but so deficient in moisture as to make it more of a liability than an asset to the state.

The climate is mild, without storms or extreme conditions of heat or cold. The growing season averages seven months, of which six months are frost-free. The rainfall averages six to seven inches on much of the region, and this does not come during the growing season. Lack of adequate rainfall upon the greater portion of the Columbia Basin is the only factor which has prevented it becoming a thriving agricultural region, for in soil and climate it is probably unequaled by a similar area in the country.

---

* The local name "Pend Oreille River" is used throughout this report. The National Geographic Board, U. S. Geological Survey, and some government maps designate this stream as "Clarks Fork."

The long days of continual sunshine, warm soil, and no rainfall during the summer, make for ideal growing conditions after irrigating water is available. The dry air and lack of storms enable harvesting to be done at the right time and without extra cost or damage due to adverse weather.

The soils are in three classes, a smooth surfaced silt-loam, a smooth surfaced lighter sandy soil, and a rougher surfaced silt-loam which by cultivation can be made equal to the first class. These classes total 1,753,000 acres of irrigable land. Adjoining these areas there are one and one-fourth million acres of land which is not suited for intensive cultivation, but which will be largely available for grazing. An additional 91,000 acres may be irrigated by pumping less than 150 feet in height, and 317,000 acres by a higher lift. Pumping areas are not included in the present estimates.

Irrigated arid areas in the West are producing crops greatly in excess of those grown in humid regions. This excess is sufficient to justify an expenditure of several hundred dollars per acre for construction of works to water these lands. The irrigated lands of Washington now reclaimed from the desert prove the value of irrigation. For a number of years the annual irrigated crop in the State of Washington has been greater in value than the entire capital cost of irrigation construction to date. From the viewpoint of state and national prosperity, irrigation would be justified if it returned in gross increased annual output but four or five per cent of its construction cost.

Unimproved lands are at present worth \$3 to \$5 an acre for grazing. The carrying of water to the land will not increase that value, excepting as development and tilling produce crops which of themselves justify a higher value. The purchase of water privileges will cost \$171.40 per acre, plus long time interest payments. Preparation of the land for irrigation will average \$15 per acre. An acre ready to plant will therefore cost about \$190, of which but \$5 or less represents the value of the raw land. *This land should not be purchased by the prospective settler until the water is ready for delivery on the land.*

This land will be comparatively easy to prepare for irrigation. It lies in nearly level prairies, with gentle slopes toward the south and practically free from the minor irregularities which would prevent efficient distribution of water. Large areas were planted to wheat during the wet cycle some years ago and will now require very little leveling before watering. These favorable conditions will tend also to lower the annual cost of irrigation.

The project will be settled as rapidly as water is available for the several units. Largely in private ownership now, with local development well advanced, transportation available throughout, agricultural conditions which will equal or excel those in the Yakima Valley; these lands will return to the settlers every year a substantial profit over all costs.

The settlement of the available humid lands of the United States compels the reclamation of other lands to provide for the increased need for food. The natural increase in farm population, aside from the immigration from abroad, requires 100,000 new farms each year. Without the provision of such farms, these prospective farmers are forced into the cities. The Columbia Basin area could be settled in a single year by the people who are now unable to obtain raw land capable of sustaining them. No such land exists in the United States except it be reclaimed by expenditure of capital in advance of settlement.

The cost of construction and operation of the irrigation system may be so apportioned as to favor the rapid development of the lands, and apply economic pressure to compel cultivation of the idle and speculatively held lands. Public supervision will be given to control prices at which settlers acquire farms and to prevent an unregulated settlement, far in advance of the distribution of water.

The following facts have been established in the study of the Columbia Basin project:

(1) There is an abundance of water that can be taken onto these lands by gravity.
(2) There are no adverse engineering features.
(3) The irrigable land is of excellent quality. Much of it has been tilled and will require small expense to prepare it for irrigation.
(4) The topography of the Columbia Basin lands lends itself to an economical distribution of water.
(5) The productivity of the land has been amply proven by results obtained from irrigation on small tracts within this area.
(6) The splendid climate, abundance of sunshine, long growing season, and the fertile lands assure abundant and dependable yields.
(7) Under present conditions, the construction cost is estimated at $171.40 per acre.

(3) *Authority.* This report upon the feasibility of irrigating the Columbia Basin is the result of many years of demand that an effort be made to place water upon the arid lands lying east of the Columbia River. The earliest explorers in the region mention the garden-like appearance of the land in the early spring and its desolation after the heat of summer has sapped away the moisture. After frequent mention on the floors of Congress and in reports upon the West, of the desirability of reclaiming these vast plains and literally creating within the State of Washington another state of equal productivity and wealth, the United States Reclamation Service in 1903 began an investigation of the engineering features involved in bringing the waters of the Spokane River and possibly of the Pend Oreille River upon these lands. After several years of preliminary examinations the Reclamation Service made an adverse report because the route then examined was not feasible.

In 1918, a proposal to carry water of Pend Oreille River to the Columbia Basin by an entirely different route was presented. In January, 1919, Governor Ernest Lister in his message to the State Legislature recommended that measures be taken to determine the merit in this project. Shortly thereafter, on March 1, 1919, Governor Louis F. Hart approved an act of the Legislature (set out in full, page 177), creating the Columbia Basin Survey Commission. The commission was directed to make suitable surveys and studies and prepare a report upon the feasibility of reclaiming the Columbia Basin. One hundred thousand dollars was provided for the expense of the work.

(4) *Organization.* The Columbia Basin Act named the State Hydraulic Engineer, *ex-officio,* as chairman of the commission and directed the Governor to appoint four additional members. This was done on March 4, 1919, and on March 20, 1919, the commission completed its organization by naming one of its members secretary. Throughout the entire work, the organization has remained as follows:

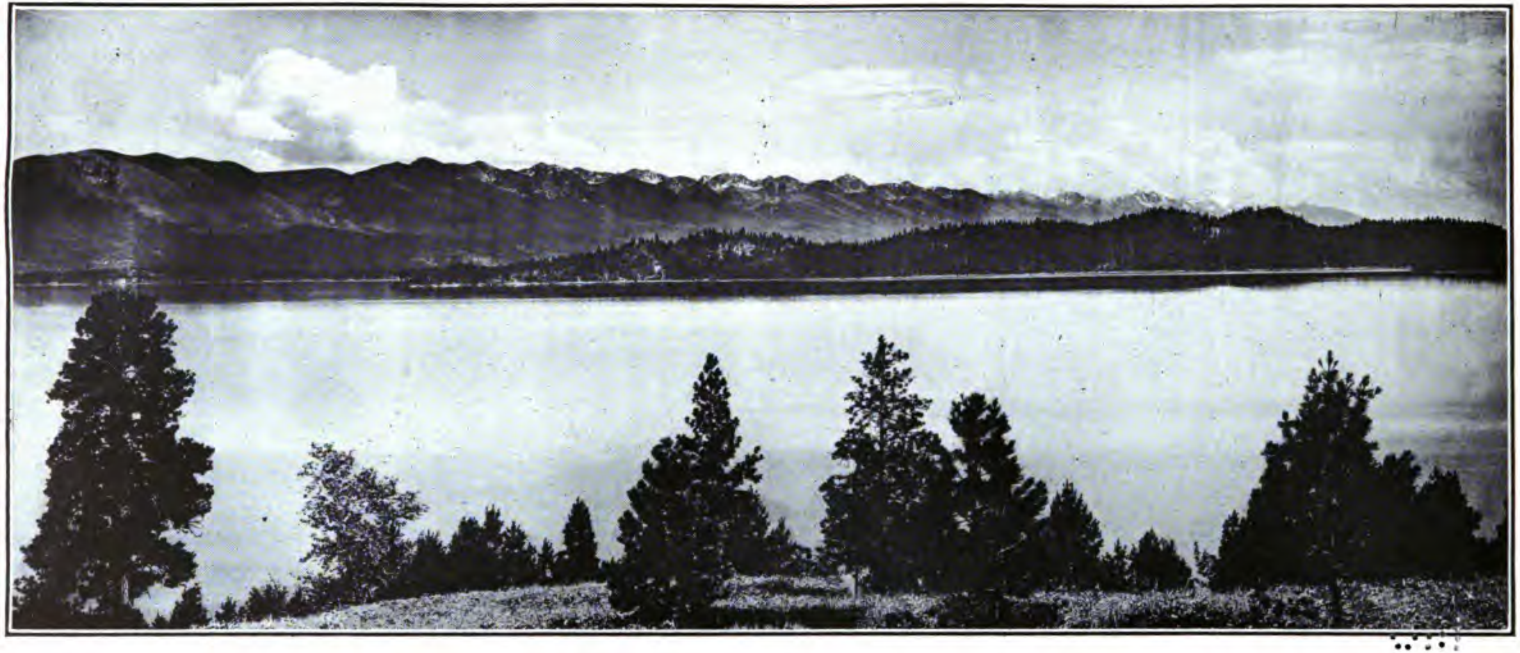
Chairman—Marvin Chase, M. Am. Soc. C. E., State Hydraulic Engineer;

Secretary—O. L. Waller, M. Am. Soc. C. E., Head of the Department of Civil Engineering, State College of Washington;

E. F. Benson, State Commissioner of Agriculture;

Peter McGregor, Director Spokane Federal Reserve Bank;

Arthur D. Jones, Investments.



FLATHEAD LAKE, MONTANA. *Photo copyrighted by H. Schnitzmeyer, Polson, Mont.*

PEND OREILLE LAKE, IDAHO.

ALBANY FALLS, IDAHO.

MU

PEND OREILLE RIVER, NEAR NEWPORT, WASHINGTON.

MU

(5) *Personnel of Staff.* The members of the staff who carried on the field operations and the office studies and designs were as follows:

Arthur J. Turner, M. Am. Soc. C. E., Chief Engineer in direct charge of the work;

J. C. Ralston, M. Am. Soc. C. E., Consulting Engineer;

Fred A. Adams, Educational Director;

Ivan E. Goodner, Office Engineer;

Lars Langloe, Field Engineer, canal location, secondary storage and the Columbia River Pumping Project;

T. H. Judd, Field Engineer, overflow and wasteways, general estimates;

O. A. Pearson, Field Engineer, canal location;

Guy C. Finley and F. W. Welch, Field Engineers, land cruising and soil classification;

Irving Worthington, Field Engineer, Wenatchee Lake Project;

J. C. Sharp, Designing Engineer;

A. D. Robinson, computations of excavation and concrete quantities.

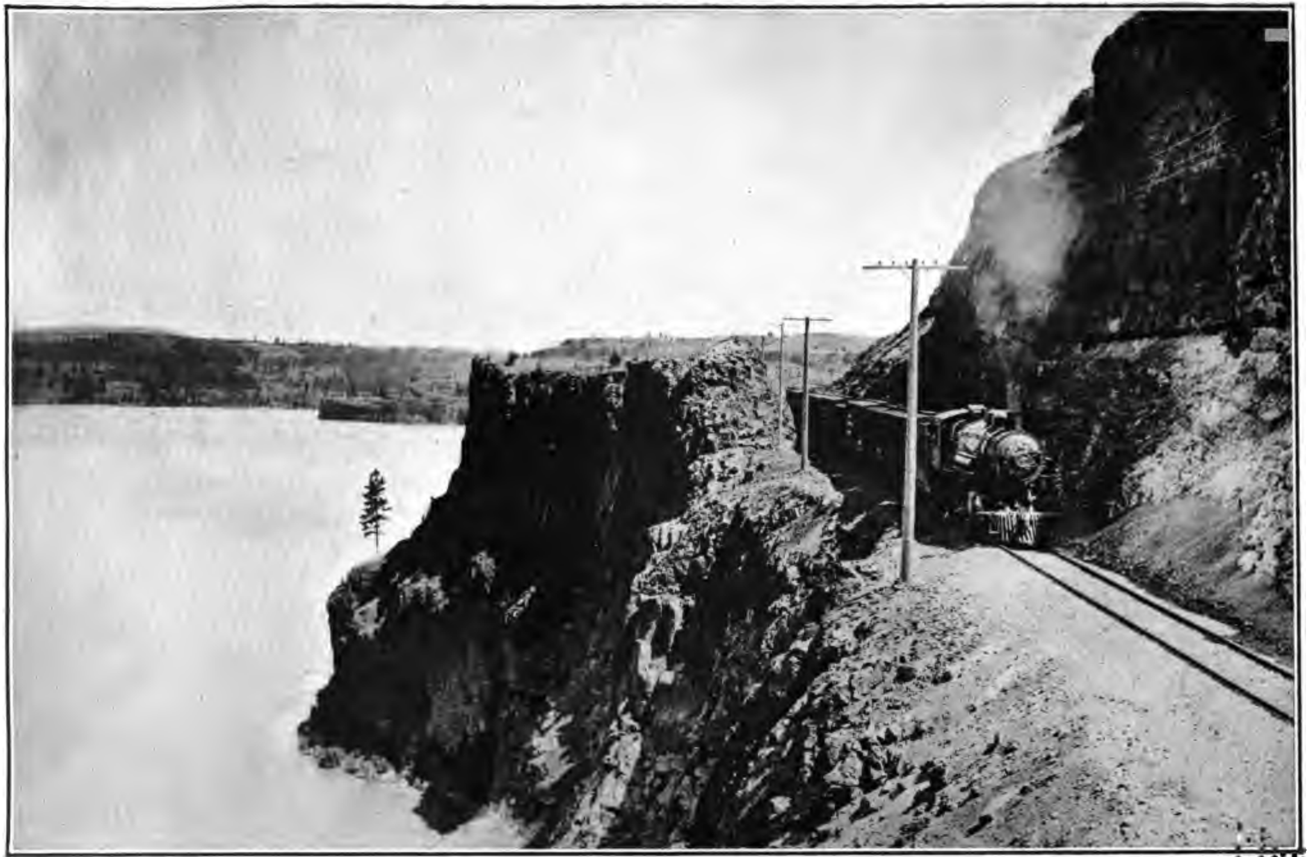
The United States Reclamation Service assigned D. C. Henny, M. Am. Soc. C. E., and James Munn as consulting engineers to cooperate in the study of general features of the work. A. J. Wiley, M. Am. Soc. C. E., was called in consultation by the commission upon questions of general design, and A. C. Dennis, M. Am. Soc. C. E., upon tunnel construction methods and costs. F. E. Weymouth, chief engineer of the United States Reclamation Service, met twice with the commission for the discussion of general methods of procedure. Henry Landes, State Geologist, dean of Department of Geology, University of Washington, and Dr. Solon Shedd, head of the Department of Geology of the State College of Washington, collaborated in an examination and report upon the proposed dam sites on the main canal and for the Columbia River pumping project.

(6) *Acknowledgments.* The commission and its staff are under a heavy debt to a large number of engineers, manufacturing and construction organizations, and others who have generously responded to requests for information, maps, reports, etc.

Among those who have so favored the commission are the Quincy Valley Irrigation District of Quincy, Washington; the United States Indian Reclamation Service; L. T. Jessup, drainage engineer of Yakima, Washington; Wm. Ashley, civil engineer, Sandpoint, Idaho; the various railroad and public utility companies of the State; all county engineers within the project or along the line of the canals; the state engineers of Oregon, Montana, Idaho, California and Colorado; the city engineers in connection with all the large aqueduct construction throughout the country, and chambers of commerce in the state. The designs and estimates furnished by the several manufacturing and construction companies have required a considerable amount of work on their part and have been of material assistance.

The United States Reclamation Service has been generous in supplying the commission with full sets of reports, standard plans of structures and detailed construction drawings of important existing structures constructed by the Service. The Water Resources Branch of the United States Geological Survey furnished the commission with a great deal of unpublished data regarding stream flow. The western offices of the United States Forestry Service and United States Weather Bureau have also furnished much information.

BONNIE LAKE, WASHINGTON.



ROCK LAKE, WASHINGTON.

CHAPTER II.

LANDS COMMANDED BY SYSTEM.

(1) *Geographic Situation.* The Columbia Basin lies east of the Columbia River and within the area inclosed by the great curve of that river as it sweeps westward from its junction with the Spokane River to the mouth of the Okanogan, southwest to the Chelan and Wenatchee rivers, thence southeast past the Yakima to its confluence with the Snake. It is tributary to all the larger cities of the Northwest—Portland, Tacoma, Seattle, Vancouver, Spokane—northern Idaho, northeastern Oregon, and western Montana, and is in the direct path of the great tides of immigration flowing to the Northwest.

(2) *Transportation Facilities.* (See frontispiece.) In the area which has been found suitable for the proposed project, there are remarkably well developed transportation facilities. In general, successful development of other large areas has been seriously handicapped by the necessity for creating transportation, rapid communication, and establishments for meeting the ordinary wants of the incoming settlers.

The Columbia Basin is traversed by five main line railways, numerous branch lines, and several state highways. Along the west and south boundaries, flow long navigable reaches of the Columbia and Snake rivers, down which it will be possible to transport the products from the land directly to Pacific ports. Four great transcontinental railways—Northern Pacific, Great Northern, Union Pacific, and Chicago, Milwaukee & St. Paul—afford direct transportation to the east and to all Pacific Coast ports. Portland, Astoria, Tacoma, Seattle, Everett, Bellingham, Victoria, and Vancouver, as well as a number of less well developed ports, are all within 200 miles of some portion of the Columbia Basin irrigable area.

The Spokane, Portland & Seattle Railway connects the coast cities with the Columbia Basin and with the rail gateway at Spokane. The Connell Northern (N. P.) between Connell, Adrian and Schrag, and the Moses Lake and Marcellus lines (C., M. & St. P.) also tap the present settled portions of the project. There are 498 miles of railway now in the district.

All the main lines named connect at Spokane with the Spokane International (Canadian Pacific System) and at Seattle, Tacoma or Portland, with the Canadian Pacific Railway to the north or the Southern Pacific Railway to the south, and the extensive lines of ocean steamships operated in connection with those roads. At all the coast cities, modern docks afford excellent connection between rail and water. All lines to Alaska, the Orient, Australia and the Pacific Islands are available, as well as the coastwise steamers through the Panama Canal to the Atlantic.

These numerous routes afford direct means of transportation between this district and the great markets of the world. The question of markets has sometimes been inadequately considered in planning the development of a large area, resulting either in the production of a crop which is already grown in excess of demand or in the growth of crops which are not susceptible of transportation to distant markets. With the direct service to foreign and eastern markets, and the large nearby city markets, neither of these adverse conditions can affect Columbia Basin producers.

(3) *Local Development.* The state and county highway improvements have already progressed far enough to provide a satisfactory farm service through a large portion of the area to be watered, and the comprehensive program now under way should keep pace with other road developments in the West.

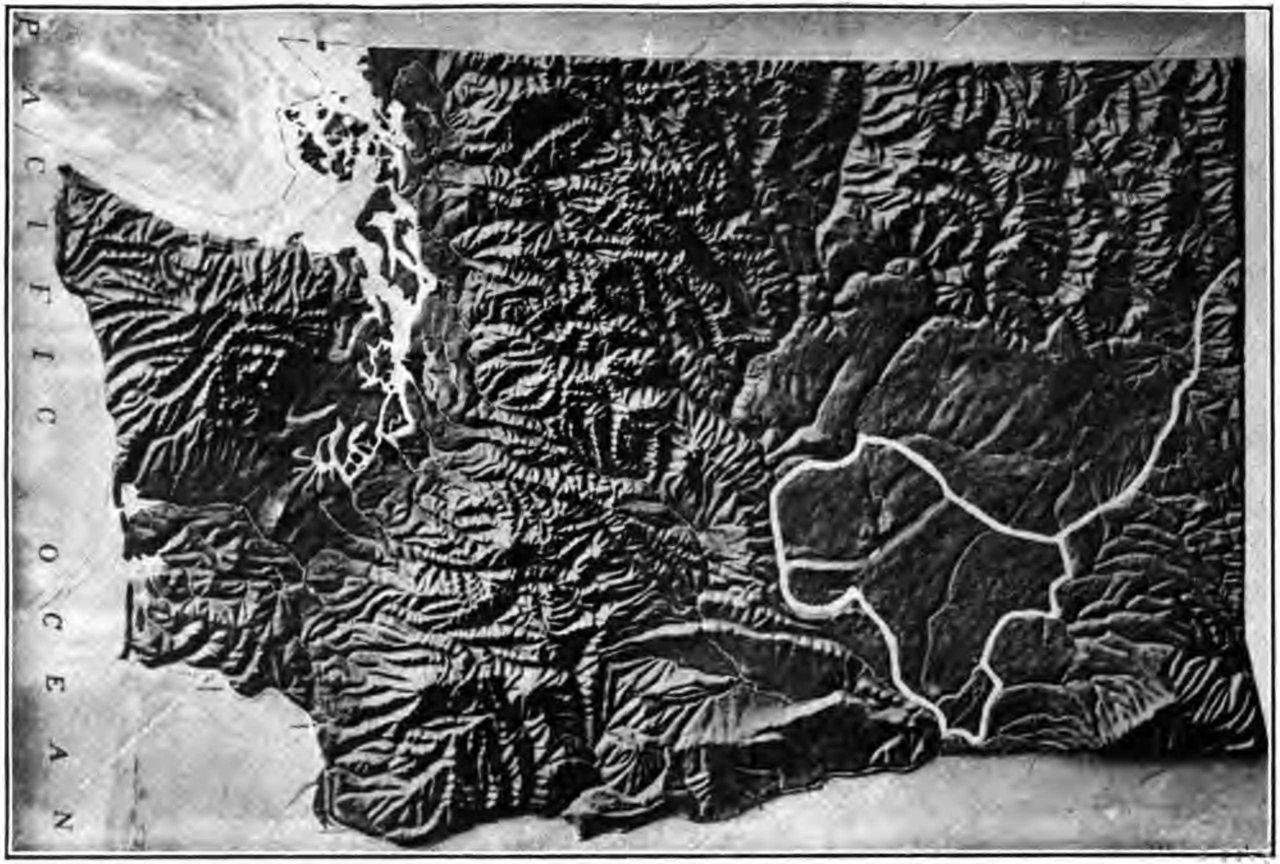
The Western Union, Postal Telegraph, and Continental Telegraph systems serve the district, having a total of 2,330 miles of wire service.

A dozen or more telephone exchanges in the project operate approximately 1,900 miles of line. Numerous farmers' lines cover the rural districts. Three high tension electric transmission lines supply present needs for power and light and have capacity sufficient for a largely increased demand.

There are numerous small towns, fifteen of which support prosperous banks. Incoming settlers will have no difficulty or delay in obtaining all necessary supplies and implements.

(4) *Crops and Markets.* The logical agricultural development of this great area will yield products for which there will always be a profitable market. Wheat, now the predominating crop, can be augmented many times without producing noticeable effect on the world's market.

Alfalfa, clovers, grasses, potatoes, corn, sugar beets, wheat, oats, barley, seeds and fruits are all well adapted to the climate and soil of this region and would produce heavy yields of high quality. Livestock products, primarily dairy and



RELIEF MAP OF STATE OF WASHINGTON.
By Dr. S. Shedd, State College of Washington. Project outline in white.

pork, would logically accompany this kind of crops and would make a well balanced intensive type of farming with staple products, a very important consideration in developing a permanent system of agriculture.

Fruits, berries, honey, and vegetables produced on the project can be marketed through growers' associations similar to those of Yakima, Wenatchee, Spokane and other irrigated districts of the Northwest. Sales may therefore be made in accordance with established methods and the entire output handled as a unit, thus eliminating the uncertainties of marketing. The large cooperative organizations in the fruit districts of the South and West have proved that successful marketing may be accomplished on any desired scale. They have gone further and shown how to create a new demand where the old was not sufficient to absorb an excessive output.

Dairying should be an important industry on the Columbia Basin Project. It is likely that a large percentage of this area will be seeded to grasses. An abundance of forage and grains and the mild climate are conducive to the promotion of a great dairy industry.

(5) *Geology.** In pre-historic times these lands constituted the bottom of a great lake, which covered all of central Washington, Yakima, Ellensburg, Wenatchee, the upper Columbia Valley, the Spokane Valley, and the wheat country of eastern Washington, and eastern and northern Oregon. Later the water broke through the Cascade Mountains and the lake gradually receded.

During this era there was deposited on the floor of this lake a deep, very rich and abundant soil. It was laid down from the disintegration and decomposition of the basaltic rocks which formed its floor and shores. This is not a series of river benches underlaid with gravel and overlaid with sand but a great blanket of fine fertile soil.

During the glacier period that followed, the Columbia River was dammed by glacial drift and was forced from its channel through the Grand Coulee. At the same time, other glaciers from the east were formed and as this great body of ice and snow melted, a splendid drainage system was opened up. The natural drainage channels then scoured out generally lead to the south and west to the Snake and Columbia rivers and provide a satisfactory and ample drainage system through which the waste waters from irrigation may find their way to the rivers without doing damage to tilled lands.

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* Russell—U. S. G. S. Bulletin 108. "A Geological Reconnaissance in Central Washington."

(6) *Climate.* Map III, "Rainfall in the State of Washington," was compiled at the State College and represents graphically the most complete information available. It will be noted that the great central area is deficient in precipitation, which ranges from six or seven inches in the arid localities, to eleven or twelve inches as the higher areas are approached on the west, north and east.

Practically all of the rain reaching the Columbia Basin area is brought by winds from the west and southwest and these winds, while saturated with moisture when they reach the western slopes of the Cascade Mountains, lose the greater part of this moisture there on account of cooling as they ascend the mountains. As they pass the summits, they are greatly depleted in moisture; and as the winds descend the eastern slopes, they are warmed and their relative humidity decreased. This results in scant precipitation over the great central area. The Columbia Basin, therefore, has many desert characteristics which are not due to soil and surface conditions, but to lack of rain. These conditions exist on the west side of the Columbia River in the Yakima and Wenatchee valleys, which are geologically the same in formation and soil as the lands east of the river.

Wonderful prosperity has come to these regions through irrigation. Water alone has caused the valley soils to produce abundantly, as well as to support a livestock industry of great value. Several small irrigation projects with local water supplies have been developed in various places throughout the Columbia Basin. These raise abundant crops, which prove that the entire Columbia Basin, given an adequate water supply, will produce as well as the parts of the state already watered.

The soil and climate of the Columbia Basin are so similar to those of the Yakima region, that the productivity of the former, given the necessary water, cannot be doubted. Tables 1 and 2 illustrate this point. The two points of importance brought out by the tables* are—first, the similarity of temperature in the Yakima and Columbia Basin regions; and second, the two weeks' longer season in the Columbia Basin area. This longer growing season is of much importance to producers of forage crops, corn and tree fruits.

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* United States Department of Agriculture, Weather Bureau, "Climatological Data," section 20 on Eastern Washington; also Annual Summary for 1918.

Table No. 1.

LENGTH OF GROWING SEASON WEST OF COLUMBIA RIVER.

STATION	Years Record	Average Date Last Killing Frost in Spring	Average Date First Killing Frost in Fall	Variation in Length Over Period Recorded	Average Length of Growing Season in Days
Wenatchee	16	Apr. 24	Oct. 24	152 to 224	183
Yakima	1	May 19	Oct. 29		163
Moxee	23	May 17	Sept. 21	82 to 175	137
Sunnyside	19	May 4	Oct. 5	86 to 188	154
Kennewick	18	Apr. 23	Oct. 15	144 to 203	175
Average					162 days

LENGTH OF GROWING SEASON EAST OF COLUMBIA RIVER.

STATION	Years Record	Average Date Last Killing Frost in Spring	Average Date First Killing Frost in Fall	Variation in Length Over Period Recorded	Average Length of Growing Season in Days
Hatton	10	May 19	Sept. 16	65 to 191	120
Lind	6	May 21	Sept. 4	106 to 170	136
Walla Walla	29	Mar. 30	Nov. 8	176 to 273	222
Trinidad	9	Apr. 7	Oct. 25	176 to 225	201
Wahluke	1	Apr. 4	Oct. 22	157 to 223	201
Ephrata	6	Apr. 22	Oct. 14	132 to 197	175
Average					176 days

Table No. 2.

MEAN TEMPERATURES, F°, WEST OF COLUMBIA RIVER.

STATION	Years Record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Mean
Wenatchee	20	25.5	29.8	39.7	48.1	55.7	62.0	69.7	67.8	59.5	49.4	37.0	27.9	49.5
Yakima	1	35.0	33.8	43.4	53.6	57.0	70.4	73.0	67.8	67.4	52.5	39.4	33.3	52.2
Moxee	24	28.5	33.8	42.6	50.4	58.2	64.6	71.3	69.5	59.9	50.0	39.3	30.7	50.0
Sunnyside	23	30.0	35.4	43.7	51.6	58.6	65.4	71.4	69.3	60.4	50.8	40.4	32.2	51.0
Kennewick	24	31.2	37.4	47.1	54.8	62.5	69.1	77.0	74.5	64.0	53.4	40.4	35.1	53.6
Average Temperature	....	....	....	....	....	....	....	....	....	....	....	....	....	51.27

MEAN TEMPERATURES, F°, EAST OF COLUMBIA RIVER.

STATION	Years Record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Mean
Hatton	14	37.5	34.0	44.0	51.5	58.3	64.6	72.8	69.1	61.0	50.7	40.2	30.4	50.7
Lind	9	30.1	32.5	41.1	50.9	58.5	65.3	73.7	73.7	62.3	51.7	39.6	30.6	50.8
Walla Walla	35	33.1	37.0	45.5	53.0	59.9	65.8	74.5	73.5	63.9	54.3	43.5	36.4	53.7
Wahluke	14	28.5	35.5	46.4	55.2	61.8	68.3	76.2	73.9	64.8	53.8	41.6	32.6	53.2
Ritzville	1	33.2	32.5	42.4	49.4	52.5	68.0	72.7	66.2	66.8	52.2	37.8	31.0	50.4
Average Temperature	....	....	....	....	....	....	....	....	....	....	....	....	....	51.76

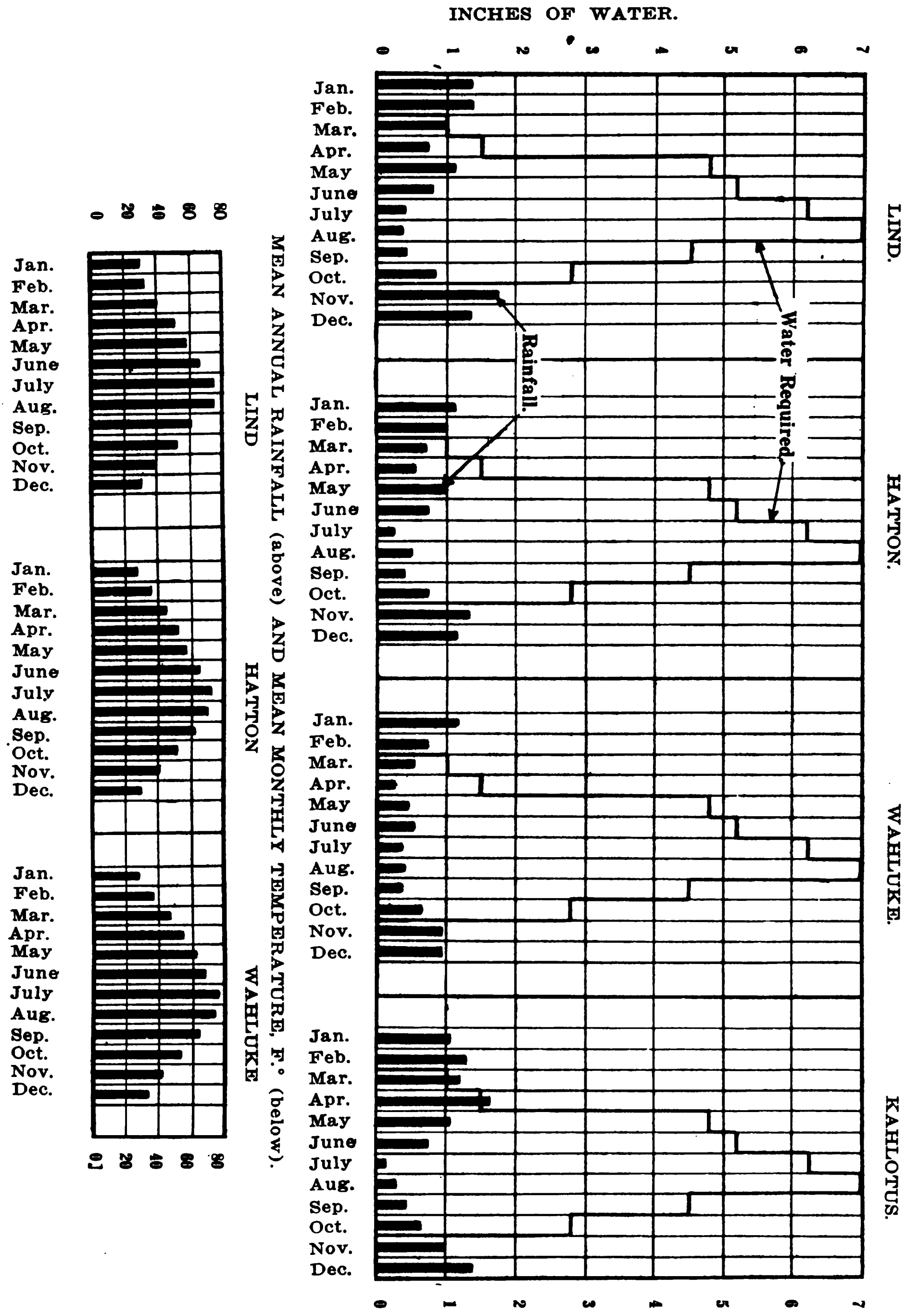
INCHES OF WATER.
0
1
2
3
4
5
6
7
LIND.
HATTON.
WAHLUKE.
KAHLOTUS.
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sep.
Oct.
Nov.
Dec.
Rainfall.
Water Required.
MEAN ANNUAL RAINFALL (above) AND MEAN MONTHLY TEMPERATURE, F° (below).
LIND
HATTON
WAHLUKE
0
20
40
60
80

FIG. 1.

The rainfall map (Map III) shows that the country east of the Columbia River receives a lower precipitation than obtains west of the river. The growing conditions on the east side are practically the same as the growing conditions on the west, which insures equal opportunities for crop production. It is evident that the lands east of the Columbia will be as much benefited by an adequate water supply as were the Yakima lands to the west of the river.

There are no destructive storms throughout the Columbia Basin. Hurricanes, tornadoes, cyclones, blizzards—all frequently encountered in much of the United States east of the Rocky Mountains—are unknown in this great northwest basin, lying between the Cascades and the Rocky Mountains. There are winds in summer and fall, typical of all arid regions.

These characteristics of climate result in an abundance of sunshine and a warm soil throughout the season of crop growth. The prevailing slope of the land is toward the southwest. This tilt toward the afternoon sun enables the soil to receive more heat than it could if lying horizontally or sloping to the north. This factor in crop growth is frequently disregarded, although irrigation experience has proven that southern slopes sustain a much more uniform crop growth than do the northern slopes.

(7) *Value of Aridity.* Only persons who have farmed in irrigated regions have a true conception of the great value of an arid climate in promoting successful agriculture. The almost continual sunshine accelerates plant growth. The soil, constantly warm, prevents any cessation of root activity which would follow night chilling. An arid climate reduces harvesting costs and insures a higher quality of products, harvested without delay or spoilage by rain.

The foregoing rainfall chart shows the negligible amount of moisture received during the growing months. This contributes largely to maximum efficiency of growth, as there is no wetting of plants at wrong periods of development. It is possible to apply irrigation water at exactly the time when it is most effective. This may be expressed as 100 per cent control of the rainfall. Publications of the United States Department of Agriculture, of the state agricultural colleges and experiment farms, and the accumulated experience of all practical irrigators, show very closely the exact time and amount of water needed by any particular kind of crop. Any departure from this need is reflected by lessened crop output. While the amount of water needed is largely determined by

the character of the soil, yet the time of watering is potent in the growth of any crop. Control by irrigation also permits any desired crop rotation, which assures perpetual fertility of the soil.

The scant rainfall of the Columbia Basin area has been very beneficial for the future irrigationist. There has not been sufficient moisture to leach away the stored plant food. At the same time, adequate drainage has prevented the accumulation of alkali salts, which are the most soluble of the earth's constituents and frequently are found in poorly drained arid regions.

(8) *Soils.* In determining the suitability for irrigation of the various soils found within the Columbia Basin area, a thorough study was made of the publications of the United States Department of Agriculture Bureau of Soils; and of the United States Department of the Interior Geological Survey Reports.* These soil surveys covered some portions of the proposed district in great detail and the descriptions and maps accompanying the reports should be of great value to the actual settler on the land.

Since, however, these publications do not include the entire area covered by the project, and also do not treat the subject from the standpoint of irrigability, it was decided that the entire area should be cruised and every section classified—first, as to whether its value would be materially increased by irrigation; and second, those lands which it was decided should be irrigated were classified into three grades, depending upon the responsiveness of the soil to irrigation.

Nearly 3,000,000 acres of land were examined and mapped, in the course of which work over 5,000 miles were traveled, exclusive of the transportation by railway. Seven hundred and sixty thousand acres were classified as non-irrigable because of scab-rock, shallow soil, pot-holes, broken surface, or because too high to reach with a gravity water supply. Three hundred seventeen thousand acres, while of good soil, were found to require a pumping lift of more than 150 feet. This land was classified as non-irrigable. The area considered as justifying irrigation is 1,753,000 acres by gravity supply and 91,000 acres by pumping lift of less than 150 feet; or a total of 1,844,000 acres. The water demand has been figured upon the basis of 1,753,000 acres under gravity irrigation.

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* Soil surveys of Walla Walla area, Quincy area, Stevens County and Franklin County; and United States Geological Survey Bulletins Nos. 118 and 316, Geology and Water Resources of east-central Washington and south-central Washington.

This area under gravity irrigation was subdivided into three groups as follows: Class "A" lands, 882,000 acres; Class "B" lands, 446,600 acres; and Class "C" lands, 424,400 acres.

Class "A" lands are defined as a silt loam soil and are superior to Class "B" with regard to soil, surface topography, and drainage. This class of lands, in general, will require very little preparation for cultivation.

Class "B" lands are defined as those that under final development will be somewhat inferior to the lands in Class "A" because of rough topography, stony or thin soil, or inferior drainage.

Class "C" lands consist, in the main, of lighter soils which would ordinarily require more than the average amount of irrigation water, but with topography as good as that of the Class "A" lands. This soil contains a larger proportion of sand and will require more water than will Class "A" or Class "B." Under proper cultivation, however, Class "C" land will produce as profitable a crop as the "A" Class. But Class "B" will never be quite as satisfactory in production as either the "A" or "C" classes.

In determining the value of soils under irrigation, comparison was made with crop returns from similar irrigated lands. Results obtained from irrigated lands in central Washington afford ample justification for the expectations placed on the Columbia Basin area. (See page 27.)

It should be understood that parts of the area classified as non-irrigable are good grazing lands and with a small amount of irrigating water may be made to yield profitable pasturage. This will assure a larger livestock production than could the irrigated farms alone. Such areas have not been counted in computing the size of canals or water storage required, since these grazing areas can be watered at times in the season when the canal is not called upon for its full capacity. In normal years, the water remaining in storage will be sufficient after the maximum demands to permit of fall irrigation of the grass areas.

There are 30,000 acres of irrigable land along the supply canal in the northern portion of Spokane County. This area was classified as 16,000 acres Class A, and 14,000 Class B. An additional 30,000 acres were examined and rejected, because not suited to irrigation. The irrigable lands have a growing season of about 100 days and could use an average water supply equal to 20 inches of rain. This quantity of

water could be furnished from the main canal without requiring an increase in its capacity. Since some of these lands are now producing fair crops and the owners may not want to be included in the Columbia Basin Project the area has been omitted from all estimates. It can be included at any future time upon payment of its proportion of costs.

(9) *Productivity of Similar Areas.* Arthur P. Davis, director of the United States Reclamation Service, is authority for the statement that western irrigated areas reclaimed by the government have averaged returns valued at $64.40 per acre as compared with average returns in humid regions of $32.10 per acre.* He states: "Out of these uninhabited and worthless deserts has been carved an empire, intensively cultivated, producing crops whose average annual gross returns per acre are about double those for the rest of the country—in other words, the average crop production of the irrigated lands of the United States is more than double the average crop production on non-irrigated lands."

Of the twelve western states showing the greatest return in value of crops per acre, Washington now leads. The irrigated areas of the state show conclusively the value of reclaiming its arid and semi-arid lands.

The following table showing crop values per acre for 1918 and 1919 in twelve arid or semi-arid states demonstrates the wealth producing capacity of these lands under irrigation:

Table No. 3. — CROP YIELDS.

(From official reports of United States Reclamation Service.)

STATE	PROJECT	1918	1919
Arizona	Yuma	113.32	134.01
Arizona	Salt River	98.70	126.27
California	Orland	58.73	71.90
Colorado	Grand Valley	64.87	64.12
Colorado	Uncompahgre	57.62	56.76
Idaho	Boise	56.80	63.12
Idaho	Minidoka	52.64	59.95
Montana	Huntley	39.00	49.14
Nebraska	North Platte	36.35	45.71
Nevada	Newlands	53.15	56.59
New Mexico	Carlsbad	60.74	106.04
Texas	Rio Grande	66.20	53.00
Oregon	Umatilla	58.75	74.83
Utah	Strawberry	55.13	67.50
Washington	Okanogan	141.85	367.23
Washington	Yakima	101.02	153.80
Wyoming	Shoshone	39.44	46.01

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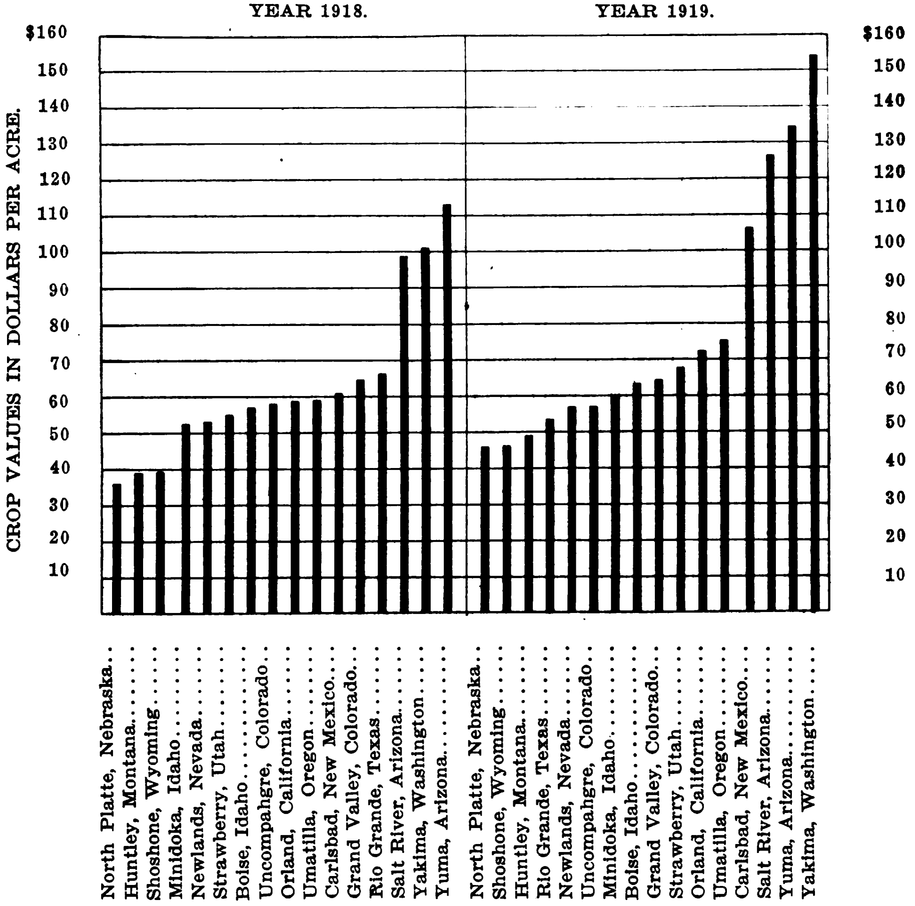
* Reclamation Record, December, 1919.

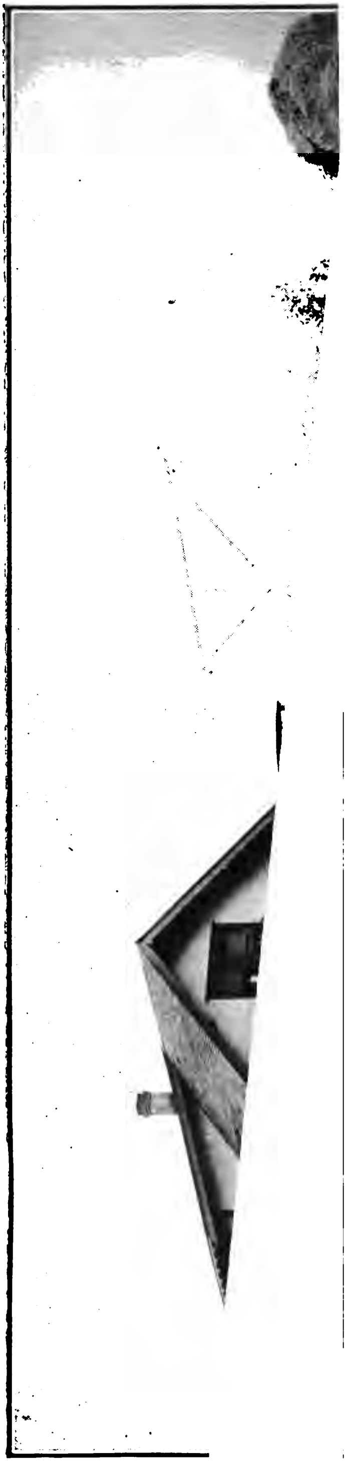
FIG. 2.

GRAPHIC PRESENTATION OF CROP VALUES FROM REPRESENTATIVE UNITED STATES RECLAMATION PROJECTS IN EACH STATE.



In estimating the value of irrigation to the Columbia Basin, it will be entirely fair to use the crop returns of the Sunnyside district in the Yakima Valley as a basis for estimates. The Federal Reclamation crop report for the Sunnyside district for 1919 showed sixty-four per cent of the project in grasses, twenty per cent in cultivated crop, and eighteen per cent in fruits. The estimated value of the crop was $167 per acre. The Sunnyside is especially suited for diversified farming.

The Columbia Basin seems eminently fitted for general agriculture. However, fruit trees do well and in places pro-



duce abundant yields. The value of the crops likely to be produced on this project may, therefore, very well be compared with the returns from the Sunnyside. Statistics furnished by farmers in the Yakima show average yields of alfalfa throughout the valley of six to seven tons per acre. The long growing season in the Columbia Basin will guarantee a yield of six tons or better. The gross returns from the Sunnyside portion of the Yakima Valley for the one year 1919 almost equaled the acre cost for water for the Columbia Basin lands. Yakima County in 1919, with a $45,000,000 crop, ranked third in the United States as a producing county.

Because of the similarity between climatic and soil conditions existing in the Yakima Valley and in the Columbia Basin, an investigation was made of crop production covering five principal crops in the Yakima Valley, namely, wheat, corn, alfalfa, potatoes and beets. Investigation shows that Yakima Valley as a whole, under irrigation, produces wheat yields averaging between 50 and 64 bushels per acre. No figures of extraordinary yields were included. The yields were based entirely upon average farming conditions by the average Yakima wheat grower. Fifty bushels of wheat per acre on Columbia Basin lands that are not now producing more than five bushels per acre, may be considered a reasonable estimate. At current prices for wheat, these lands could pay a relatively heavy water charge.

The Yakima Valley produces between 60 and 70 bushels of corn per acre. Exceptional yields under ideal conditions and intensive farming methods have produced 150 bushels of corn to the acre. The latter figure was not taken into account, however, in arriving at the general average.

The production of alfalfa varies largely in the Yakima country. Statistics furnished by many growers, however, demonstrate that the average yield throughout the valley is between 6 and 7 tons per acre.

Potatoes show a varying yield, due to different methods in cultivation. Under average conditions and average cultivation, however, the yield is ten tons per acre.

Beets are grown extensively in the valley and in years when blight does not occur the average yield is from 15 to 25 tons per acre. Beet growing, although somewhat new to the Yakima Valley, is one of the important industries.

Similarity of soil, length of growing season and climatic conditions existing in the Columbia Basin territory assure the prospective settler of crop yields equal to or surpassing those of the Yakima Valley.

(10) *Preparation of Land for Irrigation.* An item to be charged against the land, since it must be paid by each acre before the water can benefit the owner, is the cost of preparation for using the water. This is rarely thought of by farmers from naturally humid districts, but is a first and necessary cost on all irrigated areas. Clearing of sagebrush; grubbing roots; gathering and burning debris; scraping and leveling the ground surface to uniform slopes, first wetting and refilling spots where settlement occurs; building the connecting ditch to the district lateral; digging the farm laterals, and installing control gates, are all necessary before the usual operations of breaking and planting can be started. Land previously cultivated will escape that portion of these items due to clearing, but the others must be met before any crop is planted.

The expense of the preparation for irrigation varies widely, being influenced by the character of the original ground surface and by the methods employed in doing the work. Published figures* on the Yakima projects show a cost of $5 to $25 an acre, with an average of $12 to $17 in the years preceding 1903. Present conditions would at least double those figures. On the other hand, agriculturists and engineers of many years experience in the Yakima Valley, state after examination of the Columbia Basin lands, that the cost here will average half that in Yakima, or at the present time about $15 an acre. This is a direct addition in labor or cash to the purchase price of the land and must be considered in buying raw lands in any part of the project.

(11) *Arid and Irrigated Values.* The value of the arid lands in the project varies from $3 to $5 an acre for sheep grazing purposes; from $10 to $15 an acre for such lands as produce a small wheat crop in the occasional years of more than average rainfall; and from $20 to $35 an acre for improved lands favorably situated on the higher portions of the area, which are capable of producing a fair crop in alternate years if careful fallowing is practiced. Of course, there are exceptions to this general statement of values, but definite reasons must be shown to justify a sale at higher prices than the foregoing.

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* Irrigation in the Yakima Valley—United States Department of Agriculture Exp. Sta. Bulletin No. 188.

IRRIGATED CORN, YAKIMA VALLEY.

In estimating the probable value of Columbia Basin lands when water becomes available, several facts must be borne in mind. First and foremost, *the construction of irrigation works will not immediately increase the value of the lands by an amount equal to the cost of the works.* This is true because the works will ultimately have to be paid for by the land. A construction cost of $171.40 an acre should not be added to the selling value of the land until after that amount has been paid off and the land released from further liability. Until such time, the unpaid balance is a real deduction from the value of the land. Settlers on the Columbia Basin Project should clearly understand that in addition to the direct purchase of the land, they have a further debt of $171.40 an acre, plus long time interest payments, all of which they must pay during the life of the bonds. The completion of the irrigation system, therefore, while increasing the potential value of the land, adds little to the direct or true selling value.

Summing the foregoing costs—$3 to $5 an acre for sagebrush land, $15 preparation for irrigation and $171.40 water cost, totals $190, which will be the real cost of the land ready to start planting. It is difficult to find any justification for asking a higher price for the raw undeveloped land than the first mentioned values of $3 to $5 per acre. *The other costs accrue against the actual settler and farmer on the land, and he should not pay more per acre than the few dollars mentioned.*

CHAPTER III.

LAND SETTLEMENT.

The problem of prime importance is to place upon the land the actual tiller of the soil. He must first of all be of the home-building type, for experience on other reclamation projects has shown that the man who accomplishes the most in the development of an irrigated tract is the man who lives on that tract.

All published records of production, regardless of what part of the world is being studied, and regardless of the nature of the crop being produced, show that the smaller tracts average a higher output per acre than the larger tracts. The United States Reclamation Service records show that the forty-acre tract produces very much more per acre than the quarter or half section. The small tract is almost invariably cultivated personally by its owner. No hired labor ever puts the careful attention upon the land that the owner does. This is another way of saying the smaller tract receives more thorough cultivation, and this is required to fully develop the possibilities of the soil.

Again, the owner who is making his home upon the land will oftentimes foresee and avoid conditions which might be neglected by the non-resident owner or the tenant farmer to the detriment of production. By living upon the land, the owner insures the productivity of his farm, and remains there as a permanent settler; whereas, the non-resident owner or the tenant may fail to make a profit and sooner or later the land passes into other hands. Every effort should be devoted to securing settlers upon the land who are of the home-owning type. If the irrigable area were divided into forty-acre tracts, it would make homes for 44,000 families. This is equivalent to an increased population on the farms of over 200,000.

The annual increase of population in the United States rural districts is 600,000. To keep this increase on the farms would require 100,000 new farms each year, a condition which, since there are now no more free homesteads, cannot be met. The demand for land is so great, and the available lands that offer a reasonable chance for agricultural success are so scarce, that the Columbia Basin Project will be settled as rapidly as water is available for the several tracts. If the entire fifteen million acres of remaining irrigable lands in the United States are reclaimed, the natural increase in farm population would settle that area in four years. It is, therefore, impossible to develop irrigable tracts in excess of the demand, and future offerings of satisfactory lands will be immediately settled upon and brought into production.

It is especially true in the State of Washington that the complete settlement of all available humid areas is responsible for the recent lack of increase in acreage farmed. No more land remains which can be developed without reclamation. Throughout the western states the semi-arid lands were oversettled during the several years of more than average rainfall. The last few years of normal low precipitation have brought successive crop failures and the farmers have been unable to make the land support them. The continued decrease in yields on the semi-arid lands will result in their abandonment unless water is supplied with which to irrigate them.

An analysis of the ownership of the lands within the Columbia Basin Project shows the following:

Table No. 4.

ACRES OWNERSHIP—COLUMBIA BASIN LANDS.

COUNTY	PRIVATE		Govt.	State	N. P. Ry.	Total Irrigable
	Less Than Section	One Section or More				
Adams	205,230	224,980	3,660	20,790	....	454,660
Grant	332,397	248,315	59,490	26,808	52,870	719,880
Franklin	176,970	207,080	28,140	19,240	34,330	465,760
Walla Walla	38,318	61,985	5,072	5,071	2,254	112,700
Spokane	22,140	7,620	....	240	....	30,000
Total Acreage	775,055	749,980	96,362	72,149	89,454	1,783,000

Table No. 5.

PERCENTAGE DISTRIBUTION OF OWNERSHIP—COLUMBIA BASIN LANDS.

COUNTY	PRIVATE		Govt.	State	N. P. Ry.
	Less Than Section	One Section or More			
Adams	45%	49%	1%	5%	....
Grant	46%	35%	8%	4%	7%
Franklin	38%	45%	6%	4%	7%
Walla Walla	34%	55%	4.5%	4.5%	2%
Spokane	74%	25%	....	1%	....
Totals Averaged	43.5%	42.1%	5.4%	4%	5%

The above tables show that nearly half of the land is owned in tracts of less than 640 acres. If to this be added the federal, state and railroad lands, which will be disposed of in small units, it is apparent that over one-half of the total area is already in comparatively small ownership.

The gross production made by the lands held in large tracts, and the ability of lands so owned to bear their full share of the cost, are nearly the same as they would be if cut up in small holdings, with possible exception of increased production due to more intensive cultivation by the small owner. During the first few years of the operation of the system, this increase will not be so large as in later years when the differences in methods of handling have become more marked. In case the inflow of settlers should be slower than expected, there would be a very decided advantage in allowing the development of large tracts, as otherwise such areas would remain undeveloped until the arrival of the smaller holder.

The annual assessment for maintenance and operation against the undeveloped lands will result in a strong economic pressure tending to develop such lands either in their present large holdings or in subdivisions. In either event, the purpose of the project is accomplished; that is, the land is brought under cultivation. Even though a considerable portion of the land is at first developed in large holdings, the gradual breaking up of estates and the ability of the smaller holder to make a larger profit per acre and to pay a price for land which will justify the large holders in cutting up such tracts, will result in the land ultimately reaching the hands of the small, home-owning, intensive farmers.

The present owners of the land will probably put half of the total area into cultivation as rapidly as water is made available. This will leave room for about 20,000 additional farmers, until the larger tracts are broken up. With the nation-wide attention which will be attracted to the construction of one of the nation's largest projects; with the extensive advertising which will be carried on by the combined banking and commercial interests of the entire Northwest; and with the skilled and effective means of promoting immigration, exercised by the five great railroad systems which traverse the project; and with the impartial treatment which will be given every prospective settler by the official settlement commission which will have supervision and control of the project, a very rapid and satisfactory immigration into the district will result.

It is probable that unless very careful supervision and strict control are exercised to prevent residence upon the land in advance of the availability of the water, premature settlement may take place. This would result in a severe setback to the ultimate and best development of the project and must be avoided. As steps toward that end, the widest possible publicity should be given to the construction program, and maps should be prepared and distributed through every interested agency, showing exactly what areas will come under water year by year, and stating the length of time in years that the other areas must wait before water will be available.

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CHAPTER IV.

FINANCIAL AND ORGANIZATION PLANS.

(1) *General Considerations.* Solution of problems presented by organization and financing of the Columbia Basin Project has been deferred until more detailed analysis can be made. As the studies progressed and it became evident that a large amount of money would be required for the construction of the works, it was decided that these questions deserved the undivided attention of the commission and should therefore be postponed until the technical work had been completed.

Soon after the completion of this report, a series of conferences will be held with authorities on municipal law and finance. Tentative plans have already been submitted which appear to offer a feasible method of forming the several areas into an organization which will be competent either to contract for the construction of the works or itself construct the works. The plan for securing funds to meet the construction costs is dependent upon the form of organization adopted.

The commission intends to devote its energies to the immediate working out of these plans. The result of such studies, and the commission's recommendations based thereon, will be published as a supplemental report as soon as a feasible solution has been found. There are, however, certain phases of the financial plans which are closely interwoven with the use of water and the method of collecting annual charges for the water. These will be briefly discussed as they will probably not be altered by whatever plans are adopted for financing the construction costs.

(2) *Methods of Payment.* The method of charging for water will materially affect the quantity which the farmer will use. There are three common systems for delivering water to the irrigator and charging for the same: First—the water is sold upon the basis of acreage irrigated, regardless of the amount of water taken. Second—a continuous flow of water is maintained in the supply canal and the farmer may ask for delivery of water at any time desired, the charge being based upon capacity of his headgate. This method also disregards the amount actually used. Third—the charge is based upon the amount of water used. Since it is not always

feasible to measure the water to the individual user, the usual plan is to adopt some system of rotation. By rotating, the water master has a check upon the amount turned into any lateral, and since the water is allowed to run for a definite length of time, a very close estimate can be made of the quantity delivered to each farm. This enables a proportionate charge to be made and gives the farmer the benefit of the economy which he personally practices in the use of water.

Charging for the quantity used, as now practiced on some irrigation projects, plays into the hands of land speculators, who use no water on their untilled lands and who contribute nothing toward the development of the district, or toward paying for the construction and operation of the water system.

On the Columbia Basin Project, the commission recommends that a combination of charge per acre and charge for quantity of water used, be adopted. Until the construction cost has been completely paid, there will be three charges accruing each year against the land in the district—first, operation and maintenance cost; second, interest upon the unmatured bonds; and third, the redemption of the bonds maturing each year. Bond redemption will not be charged until a number of years after water is available, and then will continue until all bonds are paid. This delays the repayment of capital invested until the lands have reached full development and are easily able to meet the extra charge.

The last item is distinctly a capital charge and should be assessed against all irrigable lands regardless of stage of development. It will terminate with the final redemption of all bonded indebtedness. The second item, interest on bonds, is likewise a charge due to capital invested and should be assessed against all acreage. The interest charge will decrease as the outstanding bonds are retired, and the assessment for redemption of bonds should be increased correspondingly so that the sum of the two charges will show little variation from year to year.

The first item may be treated according to two differing principles. It is possible to charge the cost of annual operation upon the basis of the water used. This would result in an idle farm paying its share of capital redemption and interest cost, but nothing on operating cost, while the developed farm would be assessed the same capital and interest cost, plus the annual operating cost. This puts a penalty on the developed place as compared to the idle land. If the annual operating cost is charged to the idle lands as well as the developed lands, it reduces the load upon the owner who is already carrying his development costs. It also puts an economic pressure on the idle land, and tends to force it into production. Under this method, it would be advisable to charge the developed lands for a certain minimum amount of water and make an additional charge for each measured acre-foot taken in excess of that minimum. This would have the advantage of holding down the water consumption to actual requirements. It would also make the cost of the water to tilled lands less than it would be if the idle lands were not charged with their proper part of the costs.

(3) *Taxation.* Assuming that whatever method of financing is adopted for the Columbia Basin Project, all or the major part of the construction cost must ultimately be borne by the lands benefited, it is evident that the most equitable way of redeeming the invested capital is by a program involving annual taxation over a long period of years. The funds so derived would be used to pay off the outstanding bonds or to refund sums advanced by whatever financial or government organization may have made direct advances.

If the bond liability or other indebtedness is incurred at approximately the same rate as the funds so derived are expended for construction purposes, a period of several years —not less than four and probably not exceeding ten—will be covered by the inception dates of the various items of indebtedness. If each particular bond issue is divided into units maturing, say in twenty to forty years, the repayment of each portion of the construction cost will thereby be spread over a long period of time. The period of repayment will not begin to run until the development for which that particular money was expended has become fully productive.

The total payment made in any one year for combined principal, interest, and annual operating cost will amount to but a fair rate of rental for the land. After payment of the capital cost, the principal and interest payments will cease entirely, leaving thereafter only operating expenses to be met.

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CHAPTER V.

ENGINEERING SYNOPSIS.

(1) *General Outline of Studies.* The structures named on the map opposite indicate the wide range of studies that were necessary in connection with the designs and estimates. The unusually large volume of water to be diverted and controlled (equaling in seven months the average total annual flow of such rivers at the Rio Grande, Spokane, Feather, Snake, Androscoggin, or Merrimac) makes necessary the use of structures of the highest possible reliability and safety. The volume of running water requires a capacity of aqueducts, tunnels, and inverted siphons greater than any ever built. The weight of water imposes an unprecedented loading on flume floors and inverted siphons. The excessive pressure head at coulee crossings makes it impossible to carry the entire flow in a single structure.

These problems were theoretically solved after mathematical studies had indicated the proper treatment for each situation. The tentative designs were then discussed with successful contractors, construction engineers, and manufacturing companies. The adopted designs are adequate and satisfactory, although it is recognized that more elaborate and detailed analysis of the several types of structures may result in a more economical solution. So far as stability is concerned, no greater strength is needed, but it is probably possible to lower costs in some of the plans without impairing safety. The time and funds available would not permit of complete study of every alternative that might be presented.

In the technical studies, it was early found that the designs which apparently gave the most satisfactory hydraulic conditions were not always practical. For instance, pipes twenty-three feet in diameter would be highly satisfactory from the hydraulic standpoint, but in several of the locations the hydraulic pressure would be so great that the thickness of steel plate and amount of riveting required were beyond present-day practice. It, therefore, became necessary in designing the structures to sacrifice some of the desirable hydraulic features to attain a structure that could be built within the limitations of current practice. In the appendix each type of structure is discussed in detail, only the net results as to quantities and costs being carried into the body of the report.

Since all topics, other than those which are strictly engineering, are thoroughly discussed elsewhere, it is necessary here to give only an outline of the work which is reported in the several appendices, the conclusions of which have been brought forward.

In arriving at the amount of water required by the project, there was determined the quantity of water necessary for each class of soil, the area of each class, and the various losses between the points of diversion and of use. A study of the seasonal use of water on similar irrigated areas furnished a basis for estimating the monthly demand. From these data, the gross diversion was determined.

A record of water supply at several points on Pend Oreille River, extending over a number of years, showed that the available water supply was far in excess of the amount required. A comparison of the monthly demand with the monthly flow demonstrated that during the latter part of each irrigating season, the demand will be in excess of the normal flow of the river. Storage of a portion of the excess earlier flow is therefore necessary. The usual tables, hydrographs, and mass curves were constructed to determine the amount of storage advisable and after estimating the cost of creating such storage in Pend Oreille Lake and Flathead Lake and the amount of damage which would accrue to overflowed lands, the relative proportions of storage in each lake were determined.

An examination was made of water filings on the streams and sufficient investigation given the various claims, including navigation and Canadian interests, to demonstrate that no serious conflicts will exist and that the provision made for maintaining the normal low water flow of the river during the winters, and at other times not less than 7,000 cubic feet per second, will be ample to satisfy all existing rights to the water of the streams.

The various structures necessary to store and convey the water are considered in order. Concrete dams will control Flathead Lake and Pend Oreille Lake. (See illustrations opposite page 13.) These dams will be provided with large regulating gates so that the maximum flood at each point may be freely passed or any portion desired may be held in storage. At thirteen other places along the main or distributing canals, dams will be necessary. In each instance these have been designed to fit the requirements of the site.

CHAIN LAKES, NEAR CAMDEN.

At all of the dams, headgates will regulate the diversion of water into the irrigation canals. At the junctions of all canal lines, gates will be placed to control the division of water flowing into each branch. The design of these gates involved some difficulty owing to the enormous volume of water to be passed at many points, the unusually high head under which gates of such size will be required to operate, and the difficulty of providing adequate gate structures without either retarding the velocity in the canals or incurring unjustifiable expense.

In the design of the supply canal, it was evident that if the usual velocities of but two or three feet per second allowable in earth canals, were assumed, the resulting canal would be of enormous cross-section and would be practically impossible of construction or maintenance. It is also evident that with the fall available between the several controlling points —Albany Falls, Spokane River crossing and Rock Lake—it would be necessary either to introduce a large fall in drops or absorb the difference in elevation in the canal gradient. All considerations, therefore, point toward a smaller section of lined canal, a steeper grade and a higher velocity as being preferable to an unlined earthen canal.

Wherever the supply canal traverses rough country, the hexagonal section was used for the basic design. This gives the minimum quantity of excavation for a given cross section, the maximum hydraulic efficiency for a given amount of excavation, and the minimum internal surface for protection by concrete lining. As the line leaves the hills and enters the prairie regions, the section was changed to a broader and more shallow type, the ratio of breadth to depth being increased as the smaller sizes are reached.

The supply and distributing systems include the location, design and estimate of cost of all canals having a capacity of 100 second-feet or more.

The material to be excavated in the supply canal from Albany Falls to Latah Creek is nearly all earth, gravel or loose rock. From Latah Creek to Hillcrest it is practically all rock. This is evident on the surface and from the formations encountered.

Funds were insufficient for sinking test pits to determine the materials that will be encountered in the distributing mains and laterals. Thorough examination of the numerous wells, road and railway cuts near these lines enabled a satisfactory classification of materials to be made without test holes.

Concrete lining, adopted for all the canals, will maintain the banks true to the designed section and permit the use of high velocities without erosion. It also prevents burrowing animals penetrating the banks, and largely stops the seepage loss of water.

The amount of tunneling to be done is due to two conditions—first, topography of the land, making tunneling necessary; and second, the economy of a tunnel instead of an open canal at places between two adjacent canyons where the tunnel eliminates several miles of expensive canal construction along the steep mountain sides and saves the loss of grade. The grade thus saved may be utilized at some other place or it may be absorbed in the tunnel to decrease the section and cost. There are nineteen places where tunnels are either necessary or show an economy over an open canal. A concrete-lined tunnel section, having low frictional resistance, is more economical and more satisfactory than an unlined section of larger size, having a high resistance to flow.

At many of the canyons and coulees inverted siphons are the most feasible and economical crossing. On some of the large canals, where inverted siphons are under high pressure, from four to ten pipes are necessary. This multiplicity of units in each siphon is likely an advantage. The possibly greater cost and the greater loss of head, due to the smaller pipes, is partially offset by the saving in interest by making only a partial installation at the start and adding more units in later years as the demand arises for additional water.

Due to the sizes and pressure heads, all-steel siphons are more economical than reinforced concrete. Under heads of more than 90 or 100 feet, the latter requires as much metal for reinforcing as the total weight of steel pipe. This relationship is altered as the smaller capacities and lower heads are reached and under such conditions reinforced concrete may be used.

Where the canal crosses the Spokane River, a reinforced concrete aqueduct carried on concrete arches was adopted. The gradient of the canal where it crosses the river provides sufficient clearance for the passage of floods.

At the railway crossings in the Spokane Valley, the design provides for an under-pass or very short and low head inverted siphon, carrying the canal beneath the track. These structures will be of reinforced concrete and will absorb only a small amount of head. They can be easily installed and maintained without interfering with railway traffic.

Field and office studies were made looking to the development of secondary storage of water within the area to be irrigated. Such storage can be filled at times when the main canal is not otherwise carrying the full irrigation load. Such storage also acts as a catch basin to prevent waste which, due to the needs of regulation, may be turned out of the canals at a higher elevation. The water in these secondary reservoirs can be drawn on to supply lower distribution systems during the season of maximum use without adding anything to the demand on the main canals. A satisfactory development of secondary storage will enable the main canals to be built of smaller capacity with a consequent saving in cost. A correspondingly smaller primary storage in Flathead and Pend Oreille lakes is required to meet the peak load. If secondary reservoirs can be placed—as they can on this project—to pick up the wasteway water from the main canals and prevent damage in the lower water course, it is evident that from every standpoint secondary storage is highly desirable and should be as extensively and as widely distributed as the topography and nature of the land will permit.

In order that the greatest amount of land might be brought under the project, it was found necessary when locating the main canals, to save every possible foot of grade. Consequently they cross the valleys and ridges more or less at right angles. Both for economy in construction and for efficiency in reaching the maximum amount of land, the distributing canals have generally been located along the ridges. This in a number of places has resulted in an accumulation of excess grade and necessitates the use of chutes or drops.

So far as possible these drops have been located to facilitate their use for power purposes. At some of the drops economical power may be developed for pumping onto irrigable areas which are too high to be reached by gravity. The demand for water from such pumping plants will fluctuate with the demand for gravity water and the variation in power needed for pumping will be met by the corresponding changes in gravity flow at the drops. This will make the combined gravity and pumping systems self-balancing.

(2) *Alternate Routes.* The topographical sheets of the United States Geological Survey cover a portion of the Columbia Basin area. From these the general routes of the supply canal and main distributing canals were determined.

Reconnaissance surveys in the field confirmed the feasibility of such routes. Transit and level parties were then started from the controlling points—Albany Falls and Rock Lake—and careful surveys were made to determine which of the routes is the most desirable. Profiles and topographic maps were plotted, the quantities computed and estimates made of the cost of each alternate line. The index map (**Map** V) shows in outline the areas covered.

Among the more important alternate lines which are feasible but probably more expensive to construct than those adopted are the following:

Between the diversion at Albany Falls and the Little Spokane River, a canal might be constructed instead of the Newport tunnel. This route would not be chosen unless borings along the line of the latter should discover some condition which renders the tunnel construction impracticable.

At Camden, instead of following the east side of the Little Spokane Valley, the canal could be carried on the west side, past Elk, west of Chatteroy, Buckeye and Dartford. This line would pass through the northwest city limits of Spokane, through an inverted siphon at the Spokane River near Fort Wright and reach the Latah Creek damsite at a somewhat lower elevation than the line coming in from the east. On account of the loss of head, it would be necessary to increase diameter of the bore of the Bonnie Lake tunnel. This west side line does not solve the spillway problem as easily as the east line, as no lakes will be formed. Inverted siphons would be necessary in four locations. The cost of this line, however, would be practically the same as the one chosen.

Another alternative would substitute a canal from Dry Creek past Milan to Deer Creek, instead of the Milan tunnel.

The crossing of Cow Creek and the two railroads near Marengo may be accomplished by three different routes.

At nearly all of the damsites the surface conditions indicate that more than one site is possible. Furthermore, at each of the places where there is any question concerning the foundation conditions, open canal may be substituted for the dam and lake if further testing proves the site unsuitable for a dam.

The majority of the distributing canals can be placed on other suitable routes if further studies show economy in making such change. For example, the east side main canal under the Columbia River pumping project was located according to three differing grades, the highest canal or one with the least grade being estimated as the cheapest per acre watered.

Three sources of water supply for Columbia Basin lands —Pend Oreille gravity, Wenatchee gravity, and Columbia River pumping—were surveyed and studied according to the same methods, and the estimates afford a fair comparison of the relative cost per acre. The Pend Oreille project involved the estimating of seven plans, differing only in size, all using the same locations and types of structures but varying in the acreage of land covered and the amount of water required. The variations in acreage are due to the possibility of certain areas obtaining an independent water supply and therefore not requiring consideration as a part of the main project.

Figures 4 to 10 outline the areas to be included in the main project with different combinations, excluding independently watered areas. These several plans are as follows:

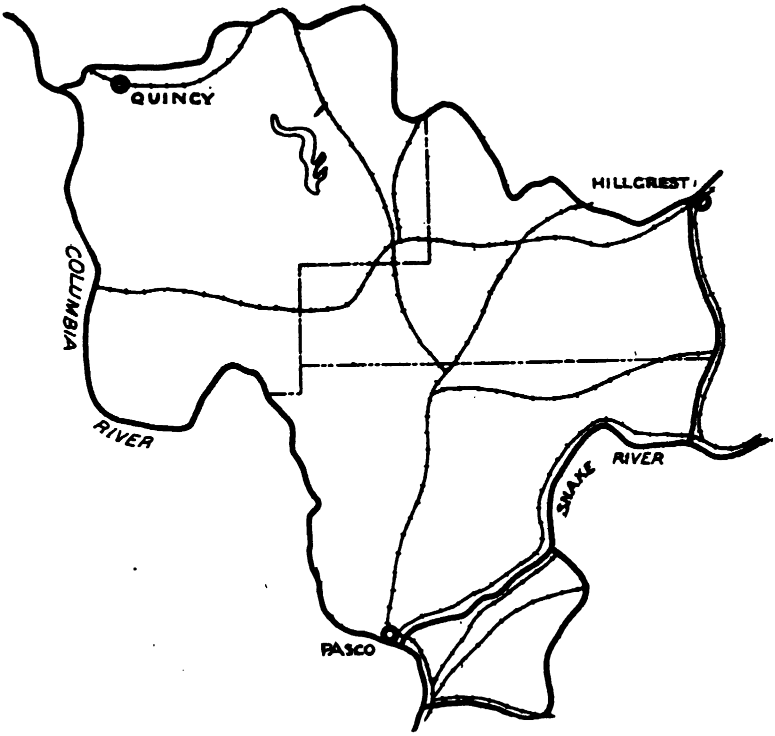

FIG. 4.

Plan I. Area, 1,753,000 acres.
Cost per acre, $171.40.
Maximum development, covering all areas that it is practical to reach from the Pend Oreille source of supply.

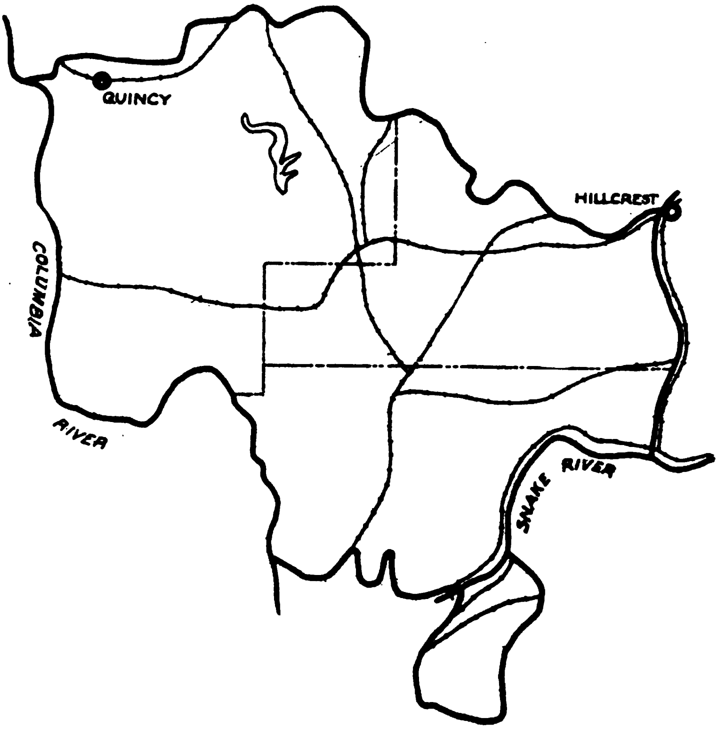

FIG. 5.

PLAN II. **Area, 1,656,700 acres.**
Cost per acre, $172.30.
Omits Five Mile area.

The Five Mile Project contemplates watering areas in Franklin and Walla Walla counties adjacent to the confluence of the Snake and Columbia rivers. It is proposed to construct a dam at the Five Mile Rapids on Snake River and install hydraulic turbines to operate pumps for lifting water to an area which will probably be less than 100,000 acres. This report designates as "South Five Mile Project" that area lying south of the Snake River below an elevation of from 600 to 550, this area being estimated at 33,000 acres. "North Five Mile Project" designates that area lying north of the Snake River and below an elevation of from 600 to 500 feet, depending upon its distance from the Snake River, this area being estimated at 62,300 acres. These areas may be too large, but there are no definite data available at this time.

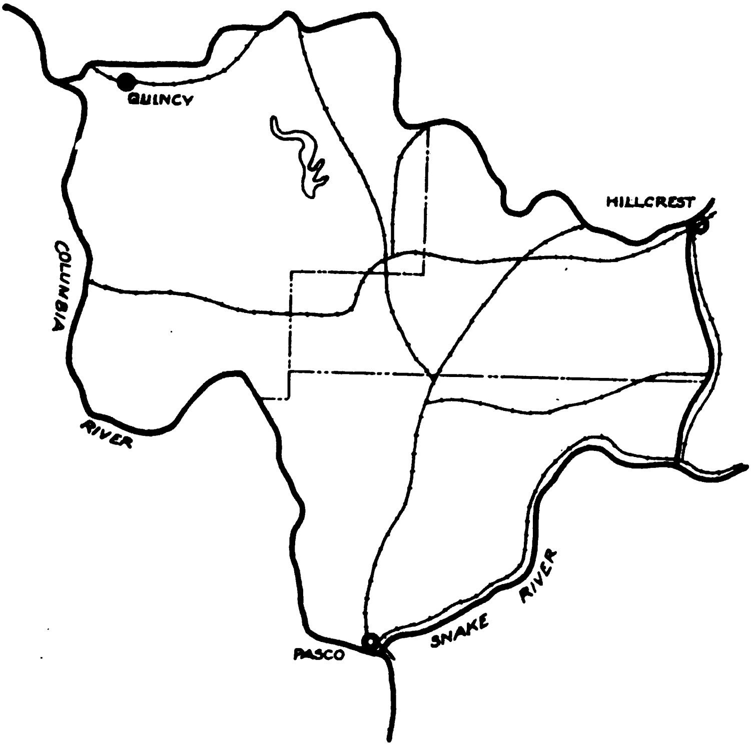

FIG. 6.

PLAN III. **Area, 1,639,300 acres.**
Cost per acre, $170.55.
Omits Eureka Flat and South Five Mile areas.

A portion of Eureka Flats may be watered in connection with storage of Touchet River water in Wynett Canyon. If this is done, the South Five Mile Project alone would not justify the expense of crossing the Snake River with the Columbia Basin canal.

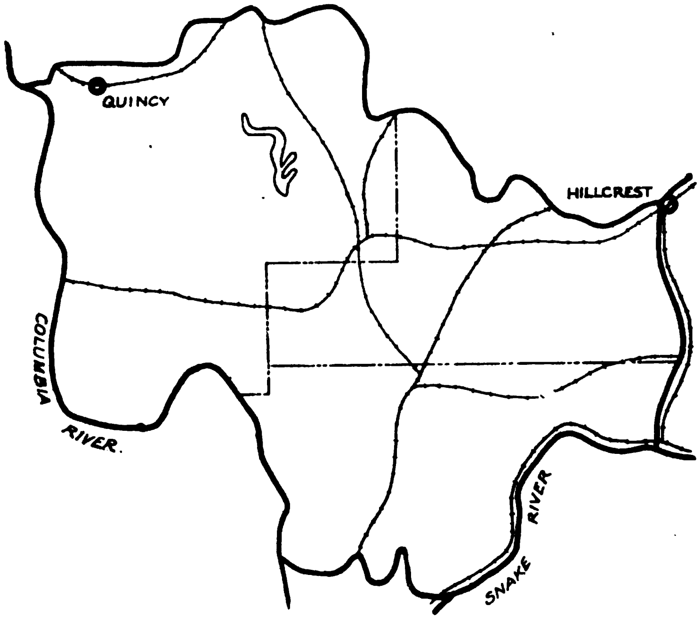

FIG. 7.

PLAN IV. Area, 1,577,000 acres.
Cost per acre, $173.05.
Omits Five Mile Project (both north and south sides)
and Eureka Flat.

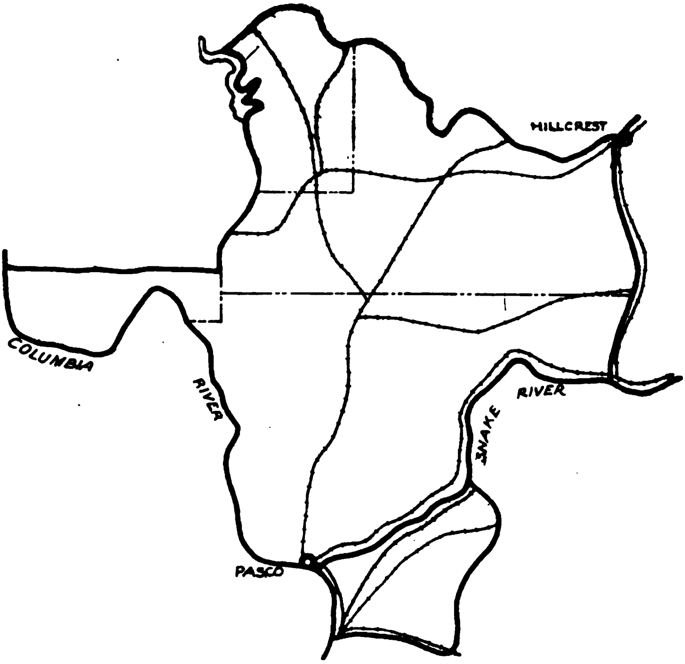

FIG. 8.

Plan V. Area, 1,328,000 acres.
Cost per acre, $172.10.
Omits Quincy area, which may obtain water from Wenatchee Lake. (See Appendix I.)

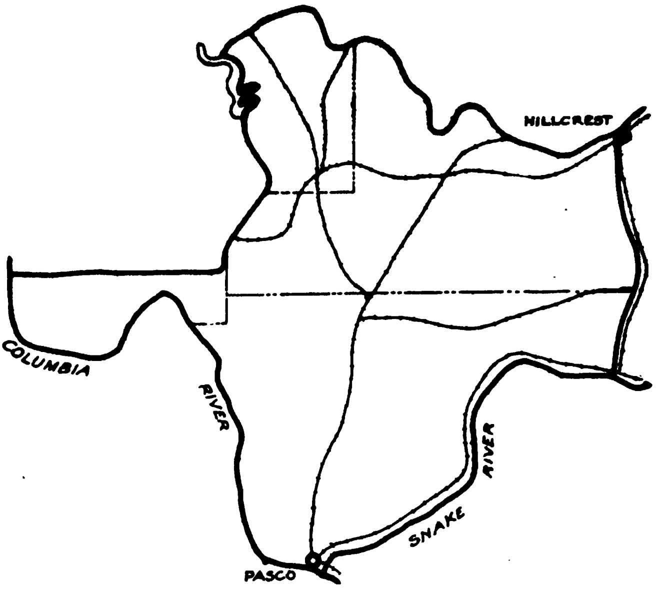

FIG. 9.

PLAN VI. Area, 1,215,300 acres.
Cost per acre, $170.65.
Omits Quincy, South Five Mile, and Eureka Flat areas.

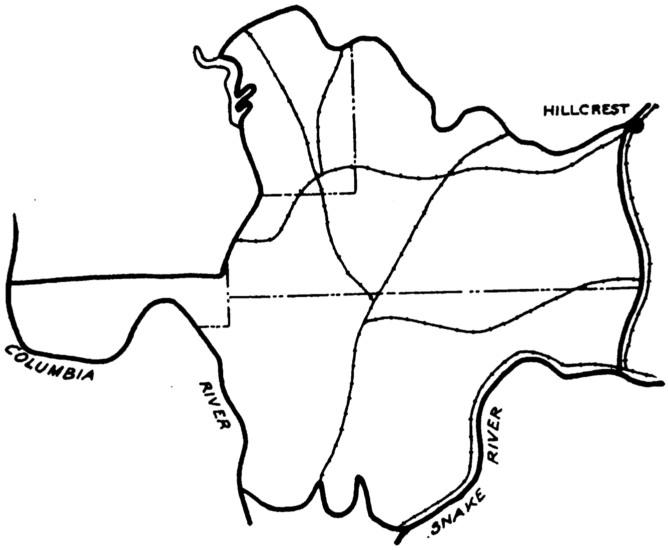

FIG. 10.

PLAN VII. Area, 1,153,000 acres.
Cost per acre, $173.25.
Omits Quincy, Five Mile, and Eureka Flat areas.

Table No. 6.

ITEMIZED COSTS, ALL PLANS UNDER PEND OREILLE SUPPLY.

PLAN	I	II	III	IV	V	VI	VII
Acreage	1,753,000	1,656,700	1,639,300	1,577,000	1,328,000	1,215,300	1,153,000
Main Supply	$159,076,355	$152,663,238	$151,875,985	$148,971,316	$137,361,940	$130,359,824	$126,513,626
North Division	57,461,163	57,653,407	57,653,407	57,653,407	15,157,568	15,157,568	15,157,568
Central Division	23,160,325	21,801,233	23,301,248	21,809,741	23,288,934	23,298,791	21,809,741
South Division	26,646,606	21,182,871	14,814,015	13,885,332	26,770,715	14,816,466	13,885,332
Distribution system below 100 second-feet capacity	26,295,000	24,850,500	24,589,500	23,655,000	19,920,000	18,229,500	17,295,000
Spillways and Wasteways, below Hillcrest	1,886,254	1,661,554	1,757,854	1,549,204	1,536,467	1,408,067	1,199,417
Minor Wasteways on Distribution System	500,000	472,000	467,000	450,000	379,000	347,000	332,000
Lateral Headgates	403,213	381,064	377,062	362,732	305,459	279,536	265,206
Road Crossings below Hillcrest	444,962	411,122	407,363	387,540	343,278	305,689	285,666
General incidentals, miscellaneous items, including patrol houses	750,000	708,000	701,000	675,000	568,000	520,000	493,000
General engineering, administration and legal expenses, preceding construction	1,051,800	994,020	983,580	946,200	796,800	729,180	691,800
Administration, legal and general expenses during construction	2,800,000	2,650,000	2,620,000	2,520,000	2,120,000	1,940,000	1,840,000
Total Cost of Project	$300,475,678	$285,429,009	$279,548,009	$272,865,472	$228,548,161	$207,391,621	$199,768,356
Cost per acre	$171.41	$172.29	$170.53	$173.03	$172.10	$170.65	$173.26

The estimates given in this report contemplate supplying the area designated as "Plan I." The six other plans have been estimated with the same detail but only the totals are published herewith. The differences in the estimates are due to the smaller capacities required for the storage reservoirs, canals, tunnels and inverted siphons. The cost of dams and rights-of-way would be practically the same. It will be observed that the reduction in area coincides so closely with the reduction in total cost, that the charge per acre shows but little variation between the seven plans.

Table No. 7.

COST OF STRUCTURES—PEND OREILLE MAXIMUM DEVELOPMENT.

Flathead Reservoir	$2,090,933
Pend Oreille Reservoir	1,194,368
Albany Falls Headgates	440,841
Newport Tunnel	18,394,255
Canal, Newport Tunnel to Chain Lakes	2,370,290
Canal, Chain Lakes to Hillcrest	25,191,161
Camden Dam	1,437,788
Dry Creek Dam	1,149,905
Milan Tunnel	8,568,410
Deep Creek Tunnel	3,856,821
Deep Creek Dam	731,807
Deadman Creek Tunnel	5,396,817
Deadman Creek Dam	3,804,747
Pleasant Prairie Tunnel	10,083,948
Spokane River Crossing	1,267,539
Manito Tunnel	10,628,080
Latah Creek Dam	2,487,754
Bonnie Lake Tunnel	46,081,166
Rock Lake Dam	2,407,471
Wassun Creek Inverted Siphon	782,588
Dragoon Lake Dam	17,659
McCall Dam and Dike	401,402
Patterson Tunnel	2,498,344
Cow Creek Inverted Siphon	2,469,286
Hillcrest Inverted Siphon and Gates	666,718
Fences, Albany Falls to Hillcrest	106,200
Telephone Lines, Albany Falls to Hillcrest	91,200
Distribution, North Division (a)	57,461,163
Distribution, Central Division (a)	23,160,325
Distribution, South Division (a)	26,646,606
Distribution, Lateral "MI"	178,080
Distribution System below 100 Second-feet Capacity	26,295,000
Spillways and Wasteways	3,027,345
Lateral Headgates	403,213
Railroad and Highway, Changes and Crossings (c)	4,084,648
General Incidentals, Miscellaneous Items, including Patrol Houses	750,000
General Engineering, Administration and Legal Expenses, preceding Construction	1,051,800
Administration, Legal and General Expense, during Construction	2,800,000
Total Cost Maximum Development	$300,475,678

(a) Does not include highway changes, which are grouped under (c).

(3) *Synopsis of Engineering Data.* (a) The water required ranges from 18 to 48 acre-inches delivered on the land, the average being 33 inches. The maximum delivery in one month will be 7 to 10 acre-inches per acre. The water loss allowed for is 5 per cent in the concrete lined canals and 15 per cent in the farm laterals. The diversion of water for the completed project will be 6,228,200 acre-feet during the

months April to October inclusive. The maximum diversion, at the rate of 20,000 cubic feet per second, will probably occur in July or August.

(b) The average flow of the Pend Oreille River at Albany Falls during the past 16 years has been 19,690,000 acre-feet per year. The minimum flow in that period was 11,000,000 acre-feet and the maximum was 29,000,000 acre-feet. Comparison of the flow of the Columbia River, to which the Pend Oreille River is tributary, with the recorded flow of the latter, shows a nearly constant percentage relationship. Applying this percentage to the Columbia River flow at The Dalles, the record of the past 41 years indicates that 11,000,000 acre-feet is the least amount the Pend Oreille has carried in any year of the 41. The water supply is therefore from two to five times the maximum required.

(c) Storage of water will be provided to equalize the flow of the stream and conserve the flood waters of the early summer for use later when the maximum demand arises from the irrigated lands. Storage can be provided in Flathead and Pend Oreille lakes. Flathead Lake will store 1,506,000 acre-feet at a cost of $1.39 per acre-foot, of which $1.02 is for overflow rights. Pend Oreille Lake will store 1,180,000 acre-feet at a cost of $1.01 per acre-foot, of which $0.36 is for overflow rights. Storage in Flathead Lake will add largely to the power possibilities in the Flathead and Clarks Fork rivers. The height of floods in these rivers will be reduced and the average flow through the irrigating season will be very largely increased. Both lakes will be prevented from reaching the usual low water elevations, but the high water elevations will not be increased. In only one year during the 16 years' record would the stored water be all used and in that year, the reservoirs would not have been completely drawn down until the last day of the irrigating season.

(d) In estimating the cost of the various portions of the work, the unit costs have been calculated under present prices of labor and materials. The size of structures and quantities of materials to be handled will permit the use of highly specialized labor-saving equipment with a consequent economy in unit costs and time. The estimate of each of the larger structures is based upon a design fitted to each particular location and the quantities have been very closely computed. Changing economic conditions may alter the estimated cost, but will not change the quantities involved.

(e) The Flathead and Albany Falls dams will be of concrete carrying large steel gates which will be opened to pass flood waters and closed to create storage. Rock fill or earthen dams have been designed for 12 to 15 other sites.

(f) Concrete lining will be placed in all canals having a capacity of 100 or more cubic feet per second. The lining will be reinforced with sufficient steel to resist the temperature stresses. Additional reinforcement will be used at the transition between cut and fill. The velocity in the main supply canals will be approximately 12.5 feet per second.

(g) All supply canal tunnels will be constructed as twin bores, concrete lined, of horseshoe section and will carry water at a velocity of 12 to 14 feet per second when running 85 per cent full. The tunnels may be constructed in sections of such length that they will be completed as soon as the other portions of the work.

(h) Canyons will be crossed by inverted siphons. Those on the main canals consist of four steel pipes each 23 feet in diameter. Reinforced concrete pipes will be used for smaller capacity and low head inverted siphons.

(i) Many special structures have been designed. The Spokane River will be crossed in a reinforced concrete flume supported by arches of the same material. Short inverted concrete siphons will pass the water under railroad crossings. Reinforced concrete or steel bridges will span the canal at all public highway crossings. Complete independent duplicate telephone systems will afford communication between all parts of the project. At many of the drops in the distributing canals, it will be possible to install power plants for pumping to areas above the gravity supply.

(j) An extensive drainage system now exists through the area to be watered. The slopes of the land are such that excess water will be immediately carried to the drainage courses, eliminating the possibility of water-logging any portion of the area with the exception of two basins near Moses Lake, which will require the early construction of small drainage ditches. Wasteway gates will permit discharge of surplus water from any of the canals into the coulees. In several of the coulees, dams may be constructed to create reservoirs. This storage of water on the project would lighten the load on the main canals during the season of greatest use of water. The lakes created along the main supply canal will give excellent control of and prevent wasting any of the water in that canal, due to regulation or shutting down of the flow.

(k) The construction of the longer tunnels on the main supply canal is the governing factor in the time required to place water on the project. It is estimated that it will require four years to drive them.

The foregoing resume affords a general view of the conditions governing the technical studies. Those interested in the engineering work are referred to the edition of this report containing a series of appendices, where details of design and quantities are given covering the following topics:

Water requirement of the lands.
Available water supply.
Conveyance of water from source to use.
Designs and estimates of structures.
Drainage and wasteways.
Secondary storage.
Power possibilities.
Recapitulation of estimates.
Columbia River pumping project.
Wenatchee Lake-Quincy project.
Reference to and index of unpublished studies and maps.

APPENDIX A.

WATER REQUIREMENT OF THE LANDS.

(1) *Water Duty.* In estimating the quantity of water required by the lands, each township was divided into the three irrigable classes of land (page 24) and a duty of water derived for each of such areas. The average figures show that from 18 to 24 acre-inches* per irrigation season will be required on class "A" lands; 24 to 36 acre-inches on class "B"; and 36 to 48 acre-inches on class "C." The above are averages of the net water actually required by alfalfa, which makes the highest demand of any growing crop. Wide variations from these figures occur in certain small areas where unusual conditions are found, as much as 60 acre-inches of water being there necessary. The average of all areas was found to be 33 acre-inches. The figures used represent an adequate supply of water for diversified farming, which it has been assumed will constitute the bulk of the development.

(2) *Water Losses.* Generally loss of water from an irrigation canal is a serious matter. At the usual rates of seepage from earth canals, eight to twenty thousand acre-feet of water per day might escape along the system. This would depend upon the character of the materials through which the canals are constructed. Such an amount of water entering the irrigated areas uncontrolled would seriously damage much of the tillable lands by raising the water table so as to injure growing crops. The canal lining provided for in the plans, for reasons discussed in the chapter on "Canals," will serve the additional purpose of preventing the seepage which normally would escape from the large and numerous ditches of an unlined system.

An extensive study of reports upon water losses from canals of many sizes has resulted in the adoption of the following estimate of losses: 5 per cent of the diverted flow in canals of 100 second-feet capacity and larger; 15 per cent of the remaining flow in the canals below 100 second-feet capacity. The net water delivered to the farms averages 80.75 per cent of the gross diversion.

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* An acre-inch is that amount of water which will cover one acre of land one inch in depth. The number of acre-inches placed upon one acre is equivalent to the same number of inches of rainfall, i. e., three acre-inches on one acre is an application equal to three inches of rain.

The evaporation from the canals is a small item in comparison to the total quantity carried.

Since no storage will be created in Flathead Lake until after the development of the first half of the irrigable area, no allowance has been made for losses due to the water distribution. Experience during the development of the first unit irrigated will supply information upon such loss. It can then be provided for in the final design for storage in Flathead Lake.

(3) *Seasonal Use of Water.* The periods during which water is delivered to the irrigated areas of the state during the growing season have been recorded for many years. From these data, together with the weather bureau reports, the average irrigation requirement for the entire district has been set at 214 days. That is, irrigation should begin in the latter part of March and continue during October. Any given locality may differ considerably in a particular year from this length of season; but experience has demonstrated that if a water supply is adequate to meet the average demand over a large area, the greater or less than average demand of any locality is offset by reverse conditions in other localities under the same system. In a similar way, the specialization of one locality in a particular type of agriculture which may create an earlier demand for water, is offset by some other area that specializes in a crop of later water requirement.

It was found that in regions having climate and soil conditions similar to the Yakima and Idaho areas, a corresponding use of water is made. Furthermore, an extensive study failed to reveal any irrigation practice of greater value to the Columbia Basin than is the practice now being followed in the adjoining Yakima district. Three hundred thousand acres in the Yakima project are now under intensive, diversified cultivation and, as discussed elsewhere, are favored with practically identical soil, climatic, topographic and economic conditions. The average use of water in the Sunnyside* unit of the Yakima Project has been adopted in the design of works for the Columbia Basin Project. In the area referred to, some irrigation takes place in March. But since the March and April demands are relatively small, they have been added together and are considered as if occurring in April. The flow in either case is so small that it can be supplied directly from the river flow, and so it does not affect the computations for reservoir storage; the reservoirs being filled from the May and June floods.

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* Etcheverry, Irrigation Practice and Engineering, Vol. 1, p. 88.

(4) *Gross Water Required.* The following table shows:
(1) The percentage of water used each month.
(2) The average use per month in acre-inches.
(3) The gross diversion in acre-feet to supply the net demand plus all losses.
(4) The gross diverted flow expressed in cubic feet per second.

Table No. 8 — WATER REQUIRED.

MONTH	Per Cent.	Acre-Inches	Gross Diversion Acre-Feet	Flow in Second-Feet
April	7.65	2.5	475,700	7,994
May	14.92	4.8	927,800	15,088
June	16.00	5.2	994,900	16,720
July	18.68	6.2	1,161,600	18,890
August	20.42	7.0	1,269,700	20,650
September	13.80	4.5	858,100	14,421
October	8.53	2.8	530,400	8,626
Totals	100.00	33.0	6,228,200	....

Two factors modify the foregoing table. First, wheat development in the Columbia Basin is probable. This will bring the maximum water demand earlier in the season than the August peak indicated by the Sunnyside records. Second, between the northern and southern parts of this project, there is a difference of several weeks in the maturity of crops. This will result in spreading over a period of several weeks the maximum water demand which occurs within a few days on any smaller area. Advancing the season's maximum demand will have a favorable effect upon storage. It will enable a larger portion of that demand to be supplied from the direct flood water of June and early July. This will maintain full storage in the reservoirs until later in the season. . If it were possible to determine more closely the exact area which will produce wheat, the provision for storage might be somewhat decreased.

Appendix B.

WATER SUPPLY AVAILABLE.

(1) *Runoff Records.* Stream flow gagings at Newport, Washington, from 1903 to 1919, inclusive, are available. These gagings are continuous except during the winter months when ice prevents reading the gage. This record is maintained by the United States Weather Bureau as a part of its flood forecasting service. Since the stream is not usually subject to winter floods, no effort is made to continue the reading during the winter. This does not make a serious break in the record, however, as the United States Geological Survey maintains a gage near Metaline Falls on the river below Newport, at which place winter readings are complete. A comparison of simultaneous readings at the two stations shows that the Newport flow averages 95 per cent of the Metaline Falls flow. A study of the intervening water-shed and of the entire water-shed above each gaging station indicates that the probable average difference between the flows at the two stations in the winter months is much less than the 5 per cent. In other words, by assuming Newport winter flow at 95 per cent of the Metaline flow, a figure results which is probably somewhat less than the true flow, but since this error is on the side of safety, and since there exists no better method of computing the actual winter runoff, these figures have been used in computing the winter runoff at Newport. Furthermore, as the normal low water flow will be permitted to pass down the stream as usual, and therefore does not affect the storage requirement, the determination of that flow is a matter of no importance.

The flow of the Pend Oreille River at Newport approximates 12 per cent of the flow of the Columbia River at The Dalles. Hydrographs of the two streams were superimposed, the scale of each being so chosen as to make the curves approximately coincide. In this way, any variations from the parallel regime of the two streams is very marked. From this study, the percentage relationship of the flow at Newport to that at The Dalles for each month of the driest years in the sixteen-year period was computed. These percentages were then applied to the monthly flows of the Columbia River in 1889, which, in the continuous record from 1879 at The Dalles, was the year of least flow. The computed flow at

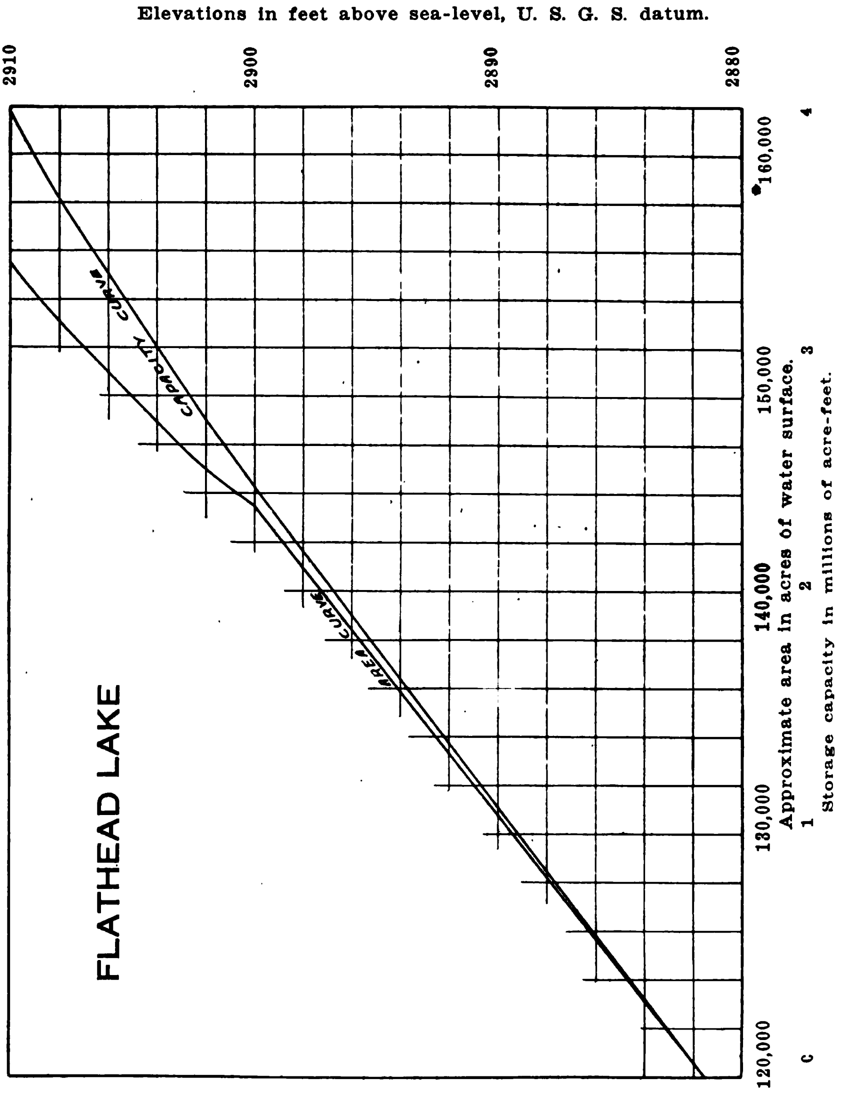

FIG. 11—AREA AND CAPACITY CURVES.

FLATHEAD LAKE.

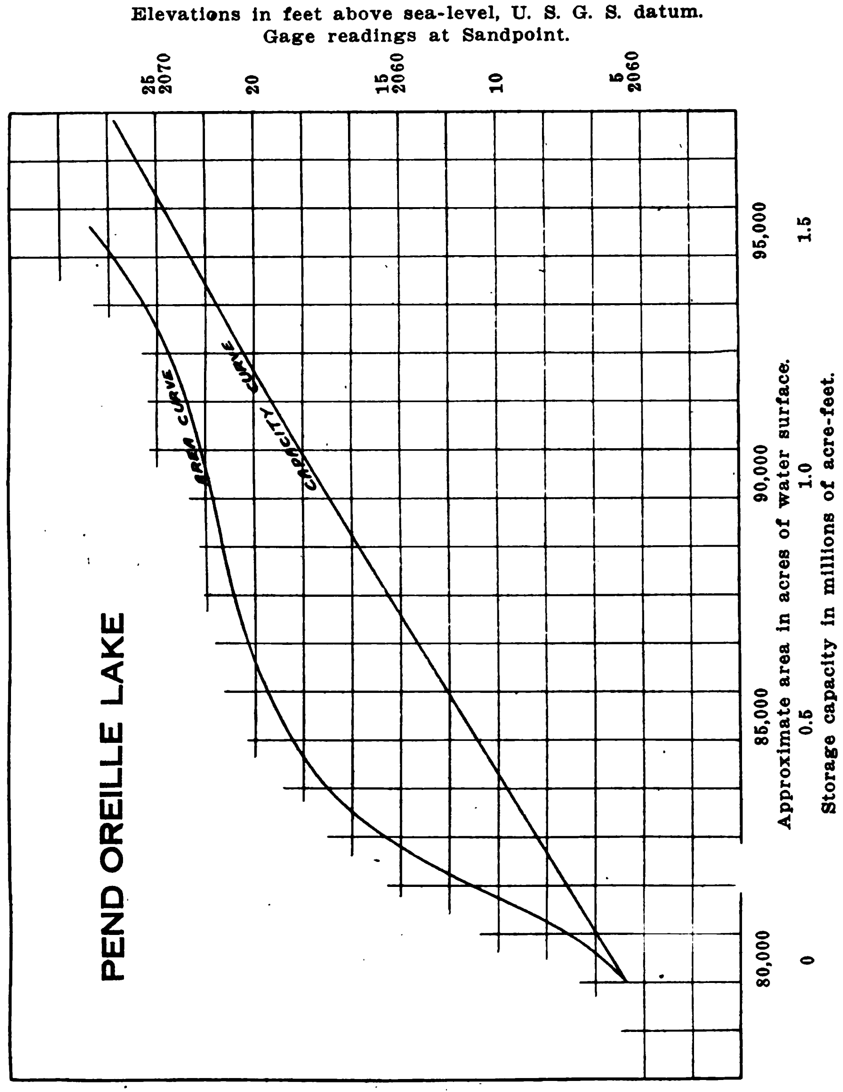

FIG. 12.— AREA AND CAPACITY CURVES.

PEND OREILLE LAKE.

Note:—Reading of 5 on Sandpoint gage equals elevation 2,050.7, U. S. G. S. datum.

Newport for 1889, thus derived from the Columbia flow, proves to be larger and better distributed than the actual gaged flow at Newport for 1919. That is, the 1919 flow at Newport represents the critical year of the sixteen years of actual gagings and forty-one years of comparative record.

(2) *Regulation by Storage.* Mass diagrams, constructed for the entire period of gagings at Newport, show four years in which a question might arise as to the adequacy of the water supply. This is due not to the total quantity of the supply, but to the fact that the monthly distribution does not coincide with the monthly crop demands. Large scale mass diagrams were therefore constructed for these four years and these diagrams were then analyzed by exhaustive tabulations of the monthly gagings of outflow, change of reservoir surface elevation, computed inflow to the reservoir, monthly demand from the irrigated lands when the project was both half and wholly developed, net resulting depth of storage, amount of storage in Pend Oreille Lake, and the ability of the stream channel above Albany Falls to carry the water required at the various stages of lake elevation. These studies conclusively show that the storage in Pend Oreille Lake to maximum surface elevation of 2,060 is adequate to supply the water demand up to 50 per cent development. The studies further show that when the district is completely developed, the storage in Pend Oreille below elevation 2,065, is inadequate.

If Pend Oreille Lake is raised above elevation 2,065, considerable additional land would thereby be flooded and damages increased. Therefore, storage in Flathead Lake is deemed advisable.

Flathead Lake has a minimum surface area of 120,000 acres and Pend Oreille Lake has a minimum of 80,000 acres. At this surface area, two feet depth of storage in Flathead practically equals three feet in Pend Oreille. With Pend Oreille Lake at elevation 2,065, there will be stored 1,180,000 acre-feet, at a cost for dam and overflowed lands of $1,194,368, which is $1.01 per acre-foot of water, and $0.68 per acre of the project. Flathead Lake at 2,893 will store 1,506,000 acre-feet, costing $2,090,933, or $1.39 per acre-foot, and $1.19 per acre irrigated.

While there exists no immediate use for Flathead water, other than for the Columbia Basin Project, yet future developments which might seriously change the regime of flow from Flathead, and adversely affect the water supply for irriga-

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Table No. 9 — WATER SUPPLY STUDY.

YEAR	MONTH	PEND OREILLE LAKE				ALL DEMANDS	ACRE-FEET REMAINING		REGULATED SURFACE ELEVATION OF	
		Outflow in Second-Feet	Outflow in Acre-Feet	Unregulated Elevation at Sand Point	Inflow in Acre-Feet	Acre-Feet	In Pend Oreille Lake	In Flathead Lake	Pend Oreille Lake	Flathead Lake
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1903	July	73,900	4,570,000	2,068.3	3,845,000	1,591,300	1,180,000	1,506,000	2,065.0	2,893.0
	August	28,900	1,780,000	2,063.0	1,389,000	1,699,500	1,180,000	1,196,000	2,065.0	2,890.6
	September	15,800	940,000	2,052.6	834,000	1,273,900	1,180,000	726,500	2,065.0	2,887.1
	October	15,500	952,000	2,052.6	925,000	960,100	1,180,000	676,700	2,065.0	2,886.7
	November	16,100	957,000	2,052.8	968,000	415,800	1,180,000	665,300	2,065.0	2,886.6
	December	16,500	1,010,000	2,052.9	1,027,000	429,700	1,180,000	665,300	2,065.0	2,886.6
1904	January	13,200	812,000	2,052.1	812,000	429,700	1,180,000	475,000	2,065.0	2,885.2
	February	11,000	633,000	2,051.6	599,000	401,940	1,180,000	170,200	2,065.0	2,882.8
	March	13,500	830,000	2,052.1	915,000	429,700	1,180,000	0	2,065.0	**
	April	31,300	1,860,000	2,056.2	2,289,000	891,500	1,180,000	0	2,065.0	**
	May	74,500	4,580,000	2,063.1	5,350,000	1,357,400	1,180,000	0	2,065.0	**
	June	85,000	5,060,000	2,064.5	5,100,000	1,410,700	1,180,000	1,506,000	2,065.0	2,893.0
	July	49,800	3,060,000	2,059.5	2,575,000	1,591,300	1,180,000	1,506,000	2,065.0	2,893.0
	August	21,500	1,320,000	2,054.0	1,029,000	1,699,500	1,180,000	835,500	2,065.0	2,887.9
	September	11,900	709,000	2,051.7	629,000	1,273,900	1,180,000	190,600	2,065.0	2,883.0
	October	9,060	557,000	2,051.1	541,000	960,100	951,500	0	2,062.3	**
	November	8,440	502,000	2,050.9	508,000	415,800	1,043,700	0	2,063.4	**
	December	8,180	503,000	2,050.9	512,000	429,700	1,126,000	0	2,064.3	**
1905	January	7,790	479,000	2,050.8	479,000	429,700	1,175,300	0	2,064.9	**
	February	7,320	406,000	2,050.7	384,000	388,080	1,171,220	0	2,064.9	**
	March	10,000	617,000	2,051.3	680,000	429,700	1,180,000	150,000	2,065.0	2,882.7
	April	12,700	756,000	2,052.0	931,000	891,500	1,180,000	150,000	2,065.0	2,882.7
	May	22,200	1,360,000	2,054.2	1,590,000	1,357,400	1,180,000	291,700	2,065.0	2,883.8
	June	43,800	2,610,000	2,058.5	2,625,000	1,410,700	1,180,000	1,506,000	2,065.0	2,893.0
	July	30,600	1,880,000	2,056.1	1,581,000	1,591,300	1,180,000	1,495,700	2,065.0	2,892.9
	August	14,100	867,000	2,052.3	520,000	1,699,500	1,180,000	316,200	2,065.0	2,884.0
	September	8,840	526,000	2,051.0	467,000	1,273,900	689,300	0	2,059.1	**
	October	9,330	574,000	2,051.1	557,000	960,100	286,200	0	2,054.2	**
	November	9,470	564,000	2,051.1	570,000	415,800	440,400	0	2,056.1	**
	December	8,510	523,000	2,050.9	532,000	429,700	542,700	0	2,057.4	**

** Periods when no stored water remains in Flathead Lake, and no record exists showing natural elevations.

Table No. 9 — WATER SUPPLY STUDY — Continued.

YEAR	MONTH	PEND OREILLE LAKE				ALL DEMANDS	ACRE-FEET REMAINING		REGULATED SURFACE ELEVATION OF	
		Outflow in Second-Feet	Outflow in Acre-Feet	Unregulated Elevation at Sand Point	Inflow in Acre-Feet	Acre-Feet	In Pend Oreille Lake	In Flathead Lake	Pend Oreille Lake	Flathead Lake
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

Table No. 9 — WATER SUPPLY STUDY — Continued.

YEAR	MONTH	PEND OREILLE LAKE				ALL DEMANDS	ACRE-FEET REMAINING		REGULATED SURFACE ELEVATION OF	
		Outflow in Second-Feet	Outflow in Acre-Feet	Unregulated Elevation at Sand Point	Inflow in Acre-Feet	Acre-Feet	In Pend Oreille Lake	In Flathead Lake	Pend Oreille Lake	Flathead Lake
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1908	July	61,900	3,810,000	2,061.8	2,953,000	1,591,800	1,180,000	1,506,000	2,065.0	2,893.0
	August	23,700	1,460,000	2,054.5	1,047,000	1,699,500	1,180,000	853,500	2,065.0	2,888.0
	September	12,500	744,000	2,051.9	645,000	1,273,900	1,180,000	224,600	2,065.0	2,883.2
	October	10,800	664,000	2,051.5	705,000	960,100	1,149,500	0	2,064.6	**
	November	11,800	702,000	2,051.7	686,000	415,800	1,180,000	0	2,065.0	**
	December	9,910	609,000	2,051.3	584,000	429,700	1,180,000	0	2,065.0	**
1909	January	10,500	646,000	2,051.4	745,000	429,700	1,180,000	0	2,065.0	**
	February	12,500	694,000	2,051.9	612,000	388,080	1,180,000	0	2,065.0	**
	March	11,400	701,000	2,051.7	733,000	429,700	1,180,000	0	2,065.0	2,879.2
	April	15,800	940,000	2,052.7	1,077,000	891,500	1,180,000	0	2,065.0	2,879.7
	May	30,800	1,890,000	2,056.1	2,398,000	1,357,400	1,180,000	0	2,065.0	2,885.8
	June	102,000	6,070,000	2,066.5	6,700,000	1,410,700	1,180,000	1,506,000	2,065.0	2,893.0
	July	68,700	4,220,000	2,062.3	3,425,000	1,591,800	1,180,000	1,506,000	2,065.0	2,893.0
	August	27,800	1,680,000	2,055.4	1,305,000	1,699,500	1,180,000	1,111,500	2,065.0	2,890.0
	September	14,200	845,000	2,052.8	733,000	1,273,900	1,180,000	570,600	2,065.0	2,885.9
	October	11,600	718,000	2,051.7	680,000	960,100	1,180,000	290,500	2,065.0	2,883.8
	November	14,700	875,000	2,053.0	1,120,000	415,800	1,180,000	290,500	2,065.0	2,883.8
	December	22,000	1,350,000	2,054.1	1,318,000	429,700	1,180,000	290,500	2,065.0	2,883.8
1910	January	17,300	1,060,000	2,053.1	912,000	429,700	1,180,000	207,000	2,065.0	2,888.1
	February	11,200	622,000	2,051.7	574,000	388,080	1,180,000	70,600	2,065.0	2,882.1
	March	27,500	1,690,000	2,055.4	2,114,000	429,700	1,180,000	0	2,065.0	2,881.5
	April	46,800	2,780,000	2,059.0	3,277,000	891,500	1,180,000	0	2,065.0	2,886.8
	May	84,500	5,200,000	2,064.5	5,274,000	1,357,400	1,180,000	1,506,000	2,065.0	2,893.0
	June	61,300	3,650,000	2,061.8	3,233,000	1,410,700	1,180,000	1,506,000	2,065.0	2,893.0
	July	30,700	1,890,000	2,056.1	1,480,000	1,591,800	1,180,000	1,394,700	2,065.0	2,892.1
	August	14,700	904,000	2,052.4	710,000	1,699,500	1,180,000	405,200	2,065.0	2,884.6
	September	10,000	595,000	2,051.8	580,000	1,273,900	891,300	0	2,061.6	2,879.6
	October	10,200	627,000	2,051.4	611,000	960,100	542,200	0	2,057.4	2,880.5
	November	14,200	845,000	2,052.8	1,055,000	415,800	1,180,000	0	2,065.0	2,881.5
	December	17,100	1,050,000	2,053.0	955,000	429,700	1,180,000	0	2,065.0	2,880.3

** Periods when no stored water remains in Flathead Lake, and no record exists showing natural elevations.

Table No. 9 — WATER SUPPLY STUDY — Continued.

		PEND OREILLE LAKE	ALL DEMANDS	ACRE-FEET REMAINING	REGULATED SURFACE ELEVATION OF

Table No. 9 — WATER SUPPLY STUDY — Continued.

YEAR	MONTH	PEND OREILLE LAKE				ALL DEMANDS	ACRE-FEET REMAINING		REGULATED SURFACE ELEVATION OF	
		Outflow in Second-Feet	Outflow in Acre-Feet	Unregulated Elevation at Sand Point	Inflow in Acre-Feet	Acre-Feet	In Pend Oreille Lake	In Flathead Lake	Pend Oreille Lake	Flathead Lake
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1913	July	69,558	4,277,100	2,062.4	3,337,100	1,591,300	1,180,000	1,506,000	2,065.0	2,893.0
	August	25,690	1,579,700	2,055.0	1,229,700	1,699,500	1,180,000	1,036,200	2,065.0	2,889.4
	September	14,130	840,700	2,052.3	720,700	1,273,900	1,180,000	483,000	2,065.0	2,885.2
	October	11,380	699,800	2,051.6	690,800	960,100	1,180,000	213,700	2,065.0	2,883.2
	November	11,970	712,200	2,051.8	736,200	415,800	1,180,000	213,700	2,065.0	2,883.2
	December	* 11,495	706,800	2,051.7	642,800	429,700	1,180,000	191,300	2,065.0	2,883.0
1914	January	* 11,495	706,800	2,051.7	745,800	429,700	1,180,000	133,900	2,065.0	2,882.6
	February	* 9,975	553,800	2,051.2	553,800	388,080	1,180,000	73,800	2,065.0	2,882.1
	March	13,190	811,100	2,052.1	866,100	429,700	1,180,000	0	2,065.0	2,879.4
	April	23,150	1,377,400	2,054.4	1,717,400	891,500	1,180,000	0	2,065.0	2,882.7
	May	56,384	3,467,100	2,060.5	3,997,100	1,357,400	1,180,000	1,200,000	2,065.0	2,890.7
	June	66,648	3,965,600	2,062.0	3,690,600	1,410,700	1,180,000	1,506,000	2,065.0	2,893.0
	July	36,340	2,234,600	2,057.2	1,799,600	1,591,300	1,180,000	1,506,000	2,065.0	2,893.0
	August	15,770	969,700	2,052.7	754,700	1,699,500	1,180,000	561,200	2,065.0	2,885.8
	September	10,220	608,100	2,051.4	563,100	1,273,900	1,030,400	0	2,063.2	2,879.9
	October	11,380	699,800	2,051.7	759,800	960,100	830,100	0	2,060.9	2,880.7
	November	17,560	1,044,800	2,053.1	1,164,800	415,800	1,180,000	0	2,065.0	2,881.3
	December	* 15,485	950,000	2,052.7	860,000	429,700	1,180,000	0	2,065.0	2,880.1
1915	January	* 10,735	660,200	2,051.5	540,200	429,700	1,180,000	0	2,065.0	2,879.6
	February	* 9,196	511,100	2,051.1	511,100	388,080	1,180,000	0	2,065.0	2,879.3
	March	9,940	610,100	2,051.2	665,100	429,700	1,180,000	0	2,065.0	2,879.4
	April	17,560	1,043,100	2,053.1	1,328,100	891,500	1,180,000	0	2,065.0	2,882.7
	May	34,410	2,112,100	2,056.8	2,325,100	1,357,400	1,180,000	753,000	2,065.0	2,887.2
	June	40,290	2,393,200	2,057.9	2,365,200	1,410,700	1,180,000	1,506,000	2,065.0	2,893.0
	July	32,970	2,023,700	2,056.5	1,853,700	1,591,300	1,180,000	1,506,000	2,065.0	2,893.0
	August	20,290	1,245,400	2,053.8	1,025,400	1,699,500	1,180,000	831,900	2,065.0	2,887.9
	September	12,270	728,800	2,051.9	663,800	1,273,900	1,180,000	221,800	2,065.0	2,883.2
	October	11,090	680,700	2,051.6	667,700	960,100	1,109,400	0	2,064.2	2,880.1
	November	11,090	658,700	2,051.6	671,700	415,800	1,180,000	0	2,065.0	2,880.1
	December	* 11,400	701,100	2,051.7	690,000	429,700	1,180,000	0	2,065.0	2,879.8

** Periods when no stored water remains in Flathead Lake, and no record exists showing natural elevations.

* Denotes quantities recorded elsewhere than at Newport. Most of these were based on readings taken at Metaline Falls. Remainder based on those taken at Plains.

Table No. 9 — WATER SUPPLY STUDY — Continued.

	PEND OREILLE LAKE	ALL DEMANDS	ACRE-FEET REMAINING		REGULATED SURFACE ELEVATION OF
	Unregulated		In	In	

Table No. 9 — WATER SUPPLY STUDY — Continued.

YEAR	MONTH	PEND OREILLE LAKE				ALL DEMANDS	ACRE-FEET REMAINING		REGULATED SURFACE ELEVATION OF	
		Outflow in Second-Feet	Outflow in Acre-Feet	Unregulated Elevation at Sand Point	Inflow in Acre-Feet	Acre-Feet	In Pend Oreille Lake	In Flathead Lake	Pend Oreille Lake	Flathead Lake
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1913	July	69,558	4,277,100	2,062.4	3,337,100	1,591,300	1,180,000	1,506,000	2,065.0	2,893.0
	August	25,690	1,579,700	2,055.0	1,229,700	1,699,500	1,180,000	1,036,200	2,065.0	2,889.4
	September	14,130	840,700	2,052.3	720,700	1,273,900	1,180,000	483,000	2,065.0	2,885.2
	October	11,380	699,800	2,051.6	690,800	960,100	1,180,000	213,700	2,065.0	2,883.2
	November	11,970	712,200	2,051.8	736,200	415,800	1,180,000	213,700	2,065.0	2,883.2
	December	* 11,495	706,800	2,051.7	642,800	429,700	1,180,000	191,300	2,065.0	2,883.0
1914	January	* 11,495	706,800	2,051.7	745,800	429,700	1,180,000	133,900	2,065.0	2,882.6
	February	* 9,975	553,800	2,051.2	553,800	388,080	1,180,000	73,800	2,065.0	2,882.1
	March	13,190	811,100	2,052.1	866,100	429,700	1,180,000	0	2,065.0	2,879.4
	April	23,150	1,377,400	2,054.4	1,717,400	891,500	1,180,000	0	2,065.0	2,882.7
	May	56,384	3,467,100	2,060.5	3,997,100	1,357,400	1,180,000	1,200,000	2,065.0	2,890.7
	June	66,648	3,965,600	2,062.0	3,690,600	1,410,700	1,180,000	1,506,000	2,065.0	2,893.0
	July	36,340	2,234,600	2,057.2	1,799,600	1,591,300	1,180,000	1,506,000	2,065.0	2,893.0
	August	15,770	969,700	2,052.7	754,700	1,699,500	1,180,000	561,200	2,065.0	2,885.8
	September	10,220	608,100	2,051.4	563,100	1,273,900	1,030,400	0	2,063.2	2,879.9
	October	11,380	699,800	2,051.7	759,800	960,100	830,100	0	2,060.9	2,880.7
	November	17,560	1,044,800	2,053.1	1,164,800	415,800	1,180,000	0	2,065.0	2,881.3
	December	* 15,485	950,000	2,052.7	860,000	429,700	1,180,000	0	2,065.0	2,880.1
1915	January	* 10,735	660,200	2,051.5	540,200	429,700	1,180,000	0	2,065.0	2,879.6
	February	* 9,196	511,100	2,051.1	511,100	388,080	1,180,000	0	2,065.0	2,879.3
	March	9,940	610,100	2,051.2	665,100	429,700	1,180,000	0	2,065.0	2,879.4
	April	17,560	1,043,100	2,053.1	1,328,100	891,500	1,180,000	0	2,065.0	2,882.7
	May	34,410	2,112,100	2,056.8	2,325,100	1,357,400	1,180,000	753,000	2,065.0	2,887.2
	June	40,290	2,393,200	2,057.9	2,365,200	1,410,700	1,180,000	1,506,000	2,065.0	2,893.0
	July	32,970	2,023,700	2,056.5	1,853,700	1,591,300	1,180,000	1,506,000	2,065.0	2,893.0
	August	20,290	1,245,400	2,053.8	1,025,400	1,699,500	1,180,000	831,900	2,065.0	2,887.9
	September	12,270	728,800	2,051.9	663,800	1,273,900	1,180,000	221,800	2,065.0	2,883.2
	October	11,090	680,700	2,051.6	667,700	960,100	1,109,400	0	2,064.2	2,880.1
	November	11,090	658,700	2,051.6	671,700	415,800	1,180,000	0	2,065.0	2,880.1
	December	* 11,400	701,100	2,051.7	690,000	429,700	1,180,000	0	2,065.0	2,879.8

** Periods when no stored water remains in Flathead Lake, and no record exists showing natural elevations.

* Denotes quantities recorded elsewhere than at Newport. Most of these were based on readings taken at Metaline Falls. Remainder based on those taken at Plains.

Table No. 9 — WATER SUPPLY STUDY — Continued.

		PEND OREILLE LAKE	ALL DEMANDS	ACRE-FEET REMAINING	REGULATED SURFACE ELEVATION OF

Table No. 9 — WATER SUPPLY STUDY — Concluded.

YEAR	MONTH	PEND OREILLE LAKE				ALL DEMANDS	ACRE-FEET REMAINING		REGULATED SURFACE ELEVATION OF	
		Outflow in Second-Feet	Outflow in Acre-Feet	Unregulated Elevation at Sand Point	Inflow in Acre-Feet	Acre-Feet	In Pend Oreille Lake	In Flathead Lake	Pend Oreille Lake	Flathead Lake
		(1)	(2)	(4)	(4)	(5)	(6)	(7)	(8)	(9)
1918	July	51,480	3,165,500	2,059.8	2,361,500	1,591,300	1,180,000	1,506,000	2,065.0	2,893.0
	August	20,290	1,247,600	2,053.8	1,032,600	1,699,500	1,180,000	839,100	2,065.0	2,887.9
	September	13,190	784,800	2,052.1	663,800	1,273,900	1,180,000	229,000	2,065.0	2,883.3
	October	9,940	611,200	2,051.3	611,200	960,100	1,060,100	0	2,063.6	2,879.6
	November	* 10,510	625,300	2,051.4	625,300	415,800	1,180,000	0	2,065.0	2,879.4
	December	* 12,840	789,500	2,051.9	789,500	429,700	1,180,000	0	2,065.0	2,879.3
1919	January	* 11,660	717,000	2,051.7	792,000	429,700	1,180,000	0	2,065.0	2,879.3
	February	* 10,580	587,600	2,051.4	490,600	388,080	1,180,000	0	2,065.0	2,879.2
	March	11,090	681,900	2,051.6	753,900	429,700	1,180,000	0	2,065.0	2,879.2
	April	21,510	1,279,800	2,054.1	1,571,800	891,500	1,180,000	0	2,065.0	2,882.6
	May	50,920	3,131,100	2,059.7	3,689,100	1,357,400	1,180,000	753,000	2,065.0	2,887.2
	June	67,251	4,001,400	2,062.1	3,701,400	1,410,700	1,180,000	1,506,000	2,065.0	2,893.0
	July	30,140	1,853,300	2,056.0	1,413,300	1,591,300	1,180,000	1,328,000	2,065.0	2,891.6
	August	12,880	792,000	2,051.9	599,000	1,699,500	1,180,000	227,500	2,065.0	2,883.3
	September	7,740	460,500	2,050.7	425,500	1,273,900	559,100	0	2,057.6	2,879.2
	October	6,500	399,700	2,050.5	399,700	960,100	0	0	2,050.5	2,878.8
	November	6,700	398,700	2,050.5	398,700	415,800	0	0	2,050.5	2,878.9
	December	* 5,100	313,500	2,050.6	313,500	429,700	0	0	2,050.6	2,878.8
1920	January	* 6,300	387,600	2,051.1	412,600	429,700	0	0	2,051.0	2,878.8
	February	* 7,885	453,200	2,050.6	428,200	401,940	26,260	0	2,051.1	2,878.9
	March	8,420	517,700	2,051.2	560,700	429,700	157,260	0	2,052.6	2,878.9
	April	12,880	766,400	2,053.3	933,400	891,500	199,160	0	2,053.2	2,880.8
	May	41,300	2,539,500	2,061.7	3,234,500	1,357,400	1,180,000	0	2,065.0	2,885.6
	June	66,025	3,928,000	2,062.8	4,022,000	1,410,700	1,180,000	1,506,000	2,065.0	2,893.0

** Periods when no stored water remains in Flathead Lake, and no record exists showing natural elevations.

* Denotes quantities recorded elsewhere than at Newport. Most of these were based on readings taken at Metaline Falls. Remainder based on those taken at Plains.

Appendix C.

CONVEYANCE OF WATER FROM SOURCE TO USE.

The general principles of design used for each class of structures, quantities involved, and estimates of unit and total costs follow. The Columbia River Pumping Project and the Wenatchee-Quincy Project are treated separately as Appendix H and Appendix I, respectively.

The variations which will be noticed in unit costs applied to any class of items are due to local conditions which affect the several structures differently. Examples: The borrow pits from which material will be obtained for a certain fill, may lend themselves to hydraulic sluicing while at another fill steam shovel excavation may be required. Free dumping ground may exist at one place, but overhaul may be required at another. Some of the structures are adjacent to railway transportation, while others will require the construction of trucking roads.

The amount of work to be done by each piece of equipment, for instance, yardage of concrete placed by a mixing and placing installation, affects the unit cost of work. Whether or not a given piece of equipment must be dismantled or can be transferred from one job to another, affects the unit cost on both jobs.

It is evident that the cost estimates throughout are modified by the program of construction. Speedy work usually means more equipment and higher unit costs to be offset against interest charges and the advantage of early completion. The water cannot be turned into the canals until the tunnels are completed, and there is therefore no advantage in hurrying other parts of the work to an earlier completion. The long tunnels will require five winters and the four intervening summers for completion, and on these speed becomes an essential factor, even though the costs may be slightly higher. All other portions of the work have been planned for the most economical construction possible, consistent with completion within the time limit set by the tunnels.

The designers have aimed to achieve stability and permanency of structures rather than maximum economy of materials. In this way the results represent practical working structures with wide margins of safety.

Sufficient details were made to support an accurate cost estimate, which, however, may be lowered by the final design, but so far as quantities are concerned, should not be exceeded.

(1) *Dams.* Topography was taken of each dam site. A geological reconnaissance was made. A field study of the conditions which would affect construction costs, and an estimate of the value of the flooded lands, were made. At several of the sites the nature of foundation was determined either by sinking test pits or by drilling. The character of the foundation and materials available for construction purposes have controlled the type of dam selected.

In most cases flood waters can be diverted into the canal, the canal capacity being far in excess of the maximum runoff. On account of existing rights below, it will be necessary in a few instances to allow the flood waters to pass down the natural stream. The decision of the Supreme Court in the case of *Still vs. Palouse Irrigation and Power Company** prevents detaining the flood waters of Rock Creek in Rock Lake. The court held that a riparian owner below the lake is entitled to the overflow of his lands by the annual flow of the stream. In such cases, sufficient spillways have been provided to pass the flood waters. Because of the importance of maintaining an adequate water supply for the irrigated district, and the fact that most of the dams are of such size that it would be impossible to replace them within a single season in the event of their destruction, every precaution has been taken in the design to insure the permanency and continuity of the water service.

Alternate designs were prepared for each site and a thorough discussion had concerning them before the recommended type was adopted. Additional studies, especially further test-pitting of the foundations and of the proposed borrow pits, may necessitate a change both in design and location of some of the dams. It is probable that further examination will show more favorable rather than less favorable conditions than those assumed.

Flathead Dam. Information furnished by the United States Geological Survey† was confirmed by field studies on Flathead Lake and Flathead River by the engineers for the Commission, and results so derived may be relied upon in connection with whatever development may be planned for the utilization of the Flathead waters.

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* 64 Washington 606, 117 Pacific 466.

† Unpublished report by C. E. LaRue on the "Power Possibilities of Flathead River."

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The "Big Rock Damsite," one and three-fourths miles below the outlet of the lake near Polson, has been chosen as best suited for the proposed development. At this place a short rapids, due to an outcropping rock barrier across the stream, furnishes an excellent site for a comparatively low dam. The bottom is practically solid rock, being a dense massive slate. The strata dip 25 to 30 degrees upstream, assuring water tightness and resistance against sliding. The double channel, due to the big rock, affords a very satisfactory condition for diverting the stream to the south channel during construction of the north end. While the big rock itself is seamed, it can be included in and made a part of the body of the dam.

Fig. 13 shows a sketch of the locality and profile of the damsite, elevation and section of the proposed dam.

Table No. 10.

COST OF FLATHEAD LAKE STORAGE.

ITEM	Unit	Quantity	Unit Cost	Cost
Coffer dam				$10,000
Solid rock excavation	Cu. Yd.	19,842	$1.50	29,763
Dam, concrete	Cu. Yd.	10,587	15.00	158,805
19.5′ x 47′ gates	No.	7	36,200.00	253,400
Regulating gates	No.	3		46,675
Structural steel for foot bridge	Lb.	66,124	.08	5,290
Engineering				20,000
				$523,933
Contingencies				30,000
Overflow rights				1,537,000
Total cost of Flathead storage				$2,090,933

Albany Falls Dam. The early reconnaissance surveys at Albany Falls were conducted by Captain Harry Taylor, United States Army Engineers, during 1897 and his report* contains a map of the falls with soundings and elevations. At various times since then, other surveys have been made. All these preceding surveys have been found to agree within themselves and to check with the detailed topographical survey of the site made by the commission's field engineers. During the period intervening between the earlier and the last surveys, the highest recorded floods on the river have passed the site without in any way changing the surface topography. The rock islets which divide the crest of the falls and also the actual crest itself have apparently remained unchanged since first observations were made many years ago. While it may be advisable to do diamond drilling before a detailed foundation design is drawn, yet there is no question concerning the perfect suitability of the site for a concrete dam.

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* Doc. 235, House of Representatives, 55th Cong.

Diversion Dam at Albany Falls. In locating the diversion dam, the most important consideration is that of providing an adequate waterway, so as not to restrict the stream channel to a greater extent than at present. The gates, as far as practicable, must be located so that openings will be in the direct line of flow of the stream.

The river channel at Albany Falls is about 1,000 feet in width with banks of solid rock, and contains two islands of solid rock. From a construction point of view, this location is an excellent damsite.

In providing sufficient waterway for flood periods the area of the cross-section of the stream was ascertained at the approximate location of the dam below an elevation of 2,060. This elevation is the height of water during the usual flood periods. This area is approximately 9,850 square feet.

The normal minimum flow, which at all times will be passed over a weir, does not exceed 7,000 second-feet.

During the maximum irrigation demand, the water surface at the intake must be maintained at not lower than 2,060.

In designing the control works, three types were considered, namely, Stoney gates, roller dams, and Taintor gates. The Taintor gates were considered least practicable. Such a structure would have to be of unprecedented dimensions. Tentative calculations indicated that the roller type dam would require an excessive amount of steel and therefore would not be economical.

In considering the Stoney gate, it was found that for a distance between piers of 50 feet and depth of water 20 to 25 feet, there are numerous examples of gates of larger dimensions, that have been constructed and are in use. This is particularly true in European designs, where for gates of these dimensions, the use of the Stoney gate is generally the established practice. That type was adopted for all the larger gates on this project.

The elevation of the sill was placed at 2,040, so that the head on the gates would be kept within the limit of economical design. The gate sill elevation must be low enough to provide sufficient area for passing flood waters when all gates are

open, without decreasing the present channel capacity. An elevation of 2,040 will satisfy both these conditions.

To provide this area of waterway during floods, it is desirable that the width of gates be made as large as practicable, thereby reducing the channel obstruction due to piers. The islands at this point greatly restrict the area of the channel. It will, therefore, be necessary to excavate a large amount of solid rock to increase the channel area, and to compensate for the water area taken up by the piers. A gate width of 50 feet is considered about the greatest practicable width that can be used for 20 to 25 depth of water. Nine such gates, capable of being lifted to a bottom clearance at 2,080, plus the weir, afford an unrestricted channel of ample capacity to pass all floods. The highest known river stage is about 2,071.

The most economical arrangement of gates and weir is to place five gates in the north channel and four in the channel between the two large rock islands, and place the weir adjacent to the south bank. This location requires considerable excavation of solid rock to provide a free and unobstructed flow to the gates. To provide a weir of suitable length to discharge 7,000 second-feet at comparatively shallow depth, it is necessary to utilize the south island and the small channel on the south side of the river. A weir 355 feet in length, passing water three feet in depth over its crest, will discharge 7,000 second-feet. To improve channel conditions and to provide a free flow over the weir, it is necessary to excavate the entire south island to five feet below the crest of weir.

These improvements will increase the capacity of the stream channel during flood periods, over that existing at the present time.

Computations were made to ascertain if enough water could be diverted from the river for partial development of the project, without constructing a diversion dam at Albany Falls, and thus reduce the initial expense of construction. One group of head gates having a sill elevation of 2,028.6, which would be the same as the tunnel invert, would require a depth of 18 feet to pass a flow of 5,000 cubic feet per second. This would require a water surface elevation of 2,046.6 feet in the river. The flow in the river is approximately 30,000 cubic feet per second for this stage of water, but is considerably below this figure for long periods during the irrigation season, so that it is manifestly impossible, without construction of a diversion dam, to divert sufficient water for even one-fourth development of the project.

Table No. 11.

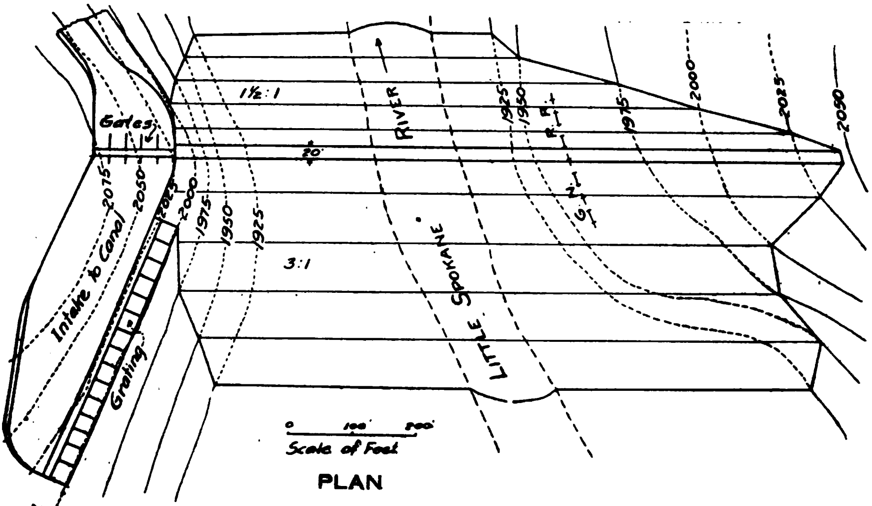
COST OF PEND OREILLE LAKE STORAGE. (Fig. 14.)

ITEM	Unit	Quantity	Unit Cost	Cost
Cofferdams, pumping, etc.				$30,000
Solid rock excavation	Cu. Yd.	114,000	$1.00	114,000
Concrete	Cu. Yd.	13,600	15.00	204,000
Structural steel towers	Lb.	373,120	.10	37,312
Structural steel 24" I beams	Lb.	86,400	.08	6,912
Dam, nine gates of structural steel	Lb.	1,530,000	.10	153,000
Cast steel hoist sheaves	Lb.	135,000	.07	9,450
Steel hoist cable	Lin. Ft.	6,696	.35	2,344
Operating mechanism, for 9 gates				144,000
Steel cable for foot bridge	Lin. Ft.	1,000	.35	350
Engineering				30,000
				$731,368
Contingencies				35,000
Overflow rights				428,000
Total cost of Pend Oreille storage				$1,194,368

Camden Dam. The canyon of the Little Spokane River will be dammed and the surface of the water raised 139 feet, at which elevation the water enters the outlet canal. This dam creates a lake four miles in length, avoids the construction of a canal along the precipitous walls of the canyon, and saves loss of head.

Two damsites near Camden were examined. The lower site would be preferable on account of creating a longer lake and eliminating several hundred feet of difficult canal construction which will be necessary if the upper site should be selected. The lower site is in a region of lake deposits or stream filled channel of unknown depth to bed rock. Churn drill holes were put down at this site and did not demonstrate a satisfactory foundation condition. It will likely be necessary to diamond drill the rock found at the bottom of several of the holes to learn whether or not it is bed rock or merely boulders. Considerable clay was found in these holes, indicating the possibility of properly sealing a cut-off wall beneath the dam. The following estimate is for a dam designed for the lower location.

Should further drilling show the lower site to be unsuited for a dam, then the upper site will be developed. At the upper location, a granite dike outcrops across the valley at right angles to the stream. The stream on the east and the railroad grade on the west side of the canyon cut 10 or 12 feet into the dike exposing the solid granite. This dike affords a perfect foundation for a dam of any height. Pressure grouting would close any cracks discovered while excavating for the foundations.



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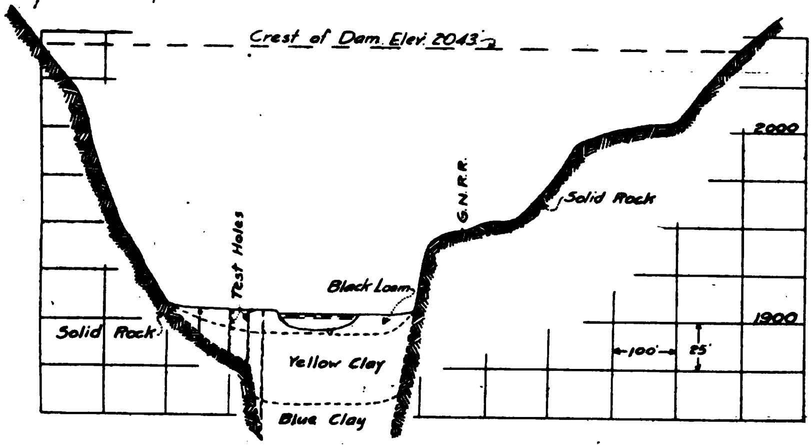

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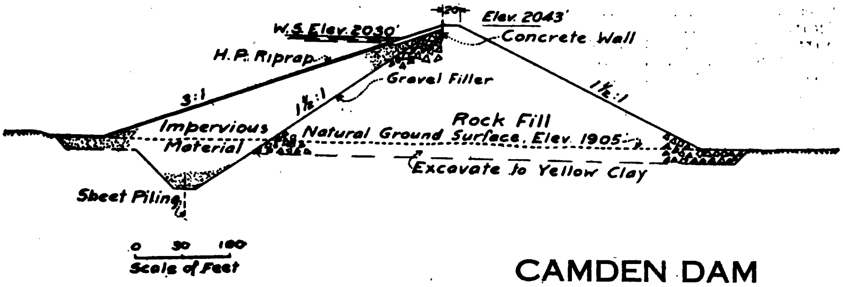


MAXIMUM SECTION

CAMDEN DAM

COLUMBIA BASIN PROJECT

STATE OF WASHINGTON

1920

FIG. 15.

Table No. 12.

COST OF CAMDEN DAM. (Fig. 15.)

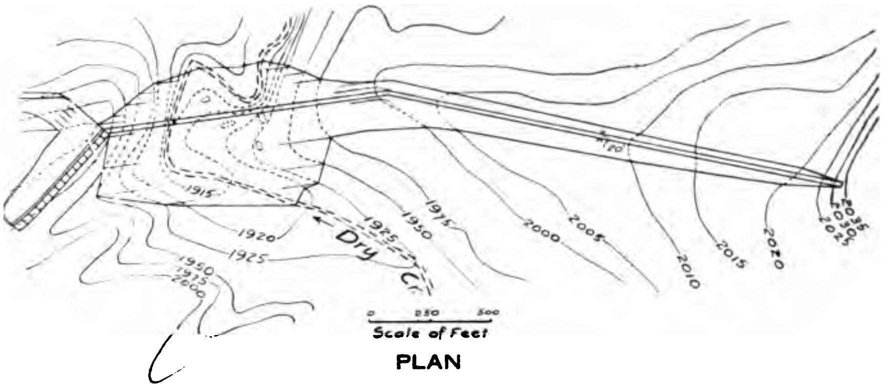
ITEM	Unit	Quantity	Unit Cost	Cost
Overflow rights	Acre	449	$20.00	$8,980
Reservoir, clearing	Acre	350	75.00	26,250
Earth excavation, stripping base	Cu. Yd.	127,093	.30	38,128
Sealing foundation	....	....	....	68,305
Rock fill, from railroad tunnel material	Cu. Yd.	364,705	.50	182,353
Rock fill, borrow	Cu. Yd.	419,261	.90	377,335
Earth fill	Cu. Yd.	315,331	.50	157,666
Stripping excavation for earth blanket	Cu. Yd.	12,000	.30	3,600
Earth blanket	Cu. Yd.	80,556	.50	40,278
Hand placed rip rap	Cu. Yd.	20,837	3.00	62,511
Preparation of rock facing	Sq. Yd.	34,626	.30	10,388
Reinforced concrete	Cu. Yd.	896	19.00	17,024
Outlet conduit	....	....	....	16,300
Outlet gates	....	....	....	303,720
Concrete roadway	Sq. Yd.	2,200	2.25	4,950
Engineering	....	....	....	40,000
				$1,357,788
Contingencies				80,000
Total cost of Camden dam				$1,437,788

Dry Creek, Deep Creek and Deadman Creek Dams. At Dry Creek, Deep Creek and Deadman Creek the construction of dams will avoid a part of the expense and loss of head due to inverted siphons or canal. The sites appear to be stream filled channels with rock sides, suitable for supporting a loose rock dam with an impervious earth blanket. The accompanying designs and estimates are self-explanatory.

Table No. 13.

COST OF DRY CREEK DAM. (Fig. 16.)

ITEM	Unit	Quantity	Unit Cost	Cost
Overflow rights	Acre	370	$30.00	$11,100
Clearing	Acre	20	100.00	2,000
Earth excavation, stripping and trench	Cu. Yd.	49,681	.30	14,904
Clay core wall	Cu. Yd.	19,240	.50	9,620
Steel sheet piling	Lb.	1,662,325	.0575	95,584
Rock fill, from tunnel excavation	Cu. Yd.	665,846	.30	199,754
Rock fill, borrow	Cu. Yd.	39,384	1.00	39,384
Preparation of rock facing	Sq. Yd.	55,331	.30	16,599
Earth fill	Cu. Yd.	277,055	.50	138,528
Stripping under earth blanket	Cu. Yd.	21,852	.50	10,926
Earth blanket	Cu. Yd.	65,555	.50	32,778
Hand placed rip rap	Cu. Yd.	46,021	3.00	138,063
Reinforced concrete	Cu. Yd.	2,575	19.00	48,925
Concrete roadway	Sq. Yd.	6,320	2.25	14,220
Outlet conduit				13,800
Outlet gates				303,720
Engineering				20,000
				$1,109,905
Contingencies				40,000
Total cost of Dry Creek dam				$1,149,905



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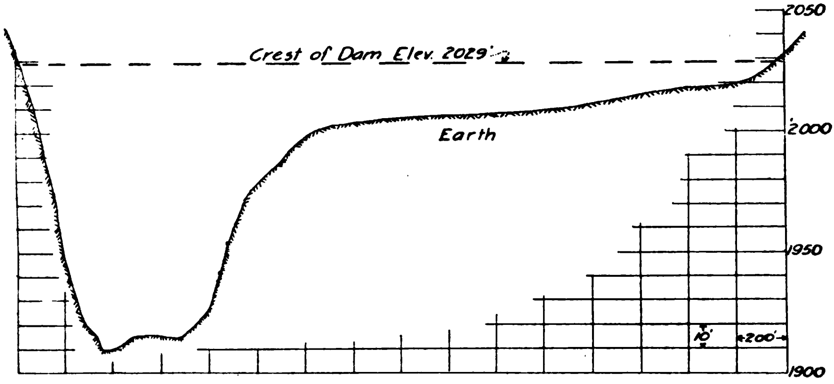

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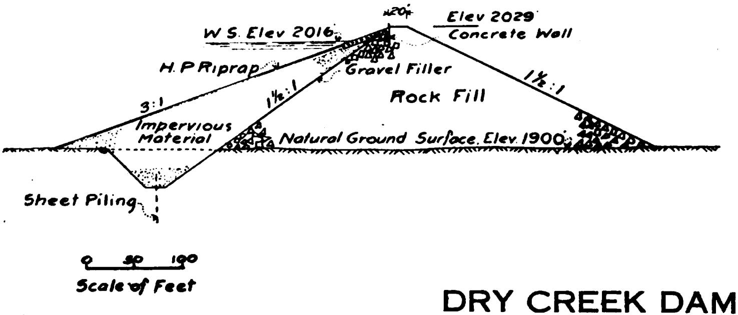


MAXIMUM SECTION

DRY CREEK DAM
COLUMBIA BASIN PROJECT
STATE OF WASHINGTON
1920

FIG. 16.

Table No. 14.

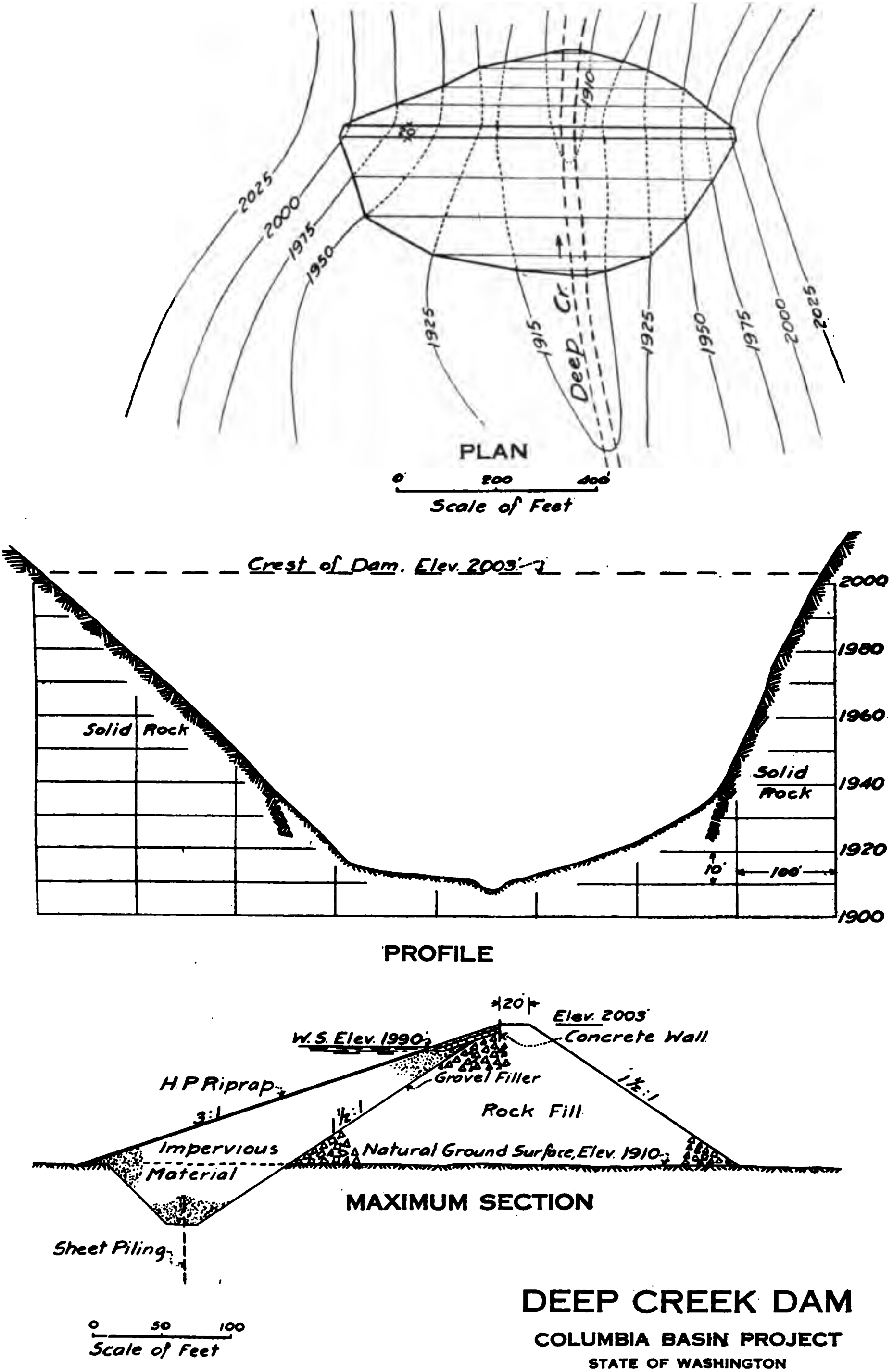
COST OF DEEP CREEK DAM. (Fig. 17.)

ITEM	Unit	Quantity	Unit Cost	Cost
Overflow rights	Acre	930	$100.00	$93,000
Clearing	Acre	100	75.00	7,500
Earth excavation, stripping	Cu. Yd.	18,661	.30	5,598
Earth excavation, sealing trench	Cu. Yd.	7,067	.50	3,534
Concrete core wall	Cu. Yd.	195	19.00	3,705
Rock fill from Deep Creek tunnel	Cu. Yd.	276,576	.35	96,802
Earth fill	Cu. Yd.	103,187	.50	51,594
Preparation of rock face	Sq. Yd.	18,114	.30	5,354
Stripping under earth blanket	Cu. Yd.	45,630	.30	13,689
Earth blanket	Cu. Yd.	68,444	.50	34,222
Hand placed rip rap	Cu. Yd.	12,137	3.00	36,411
Outlet conduit				11,300
Outlet gates				303,720
Reinforced concrete	Cu. Yd.	627	19.00	11,913
Concrete roadway	Sq. Yd.	1,540	2.25	3,465
Engineering				15,000
				$696,807
Contingencies				35,000
Total cost of Deep Creek dam				$731,807

Table No. 15.

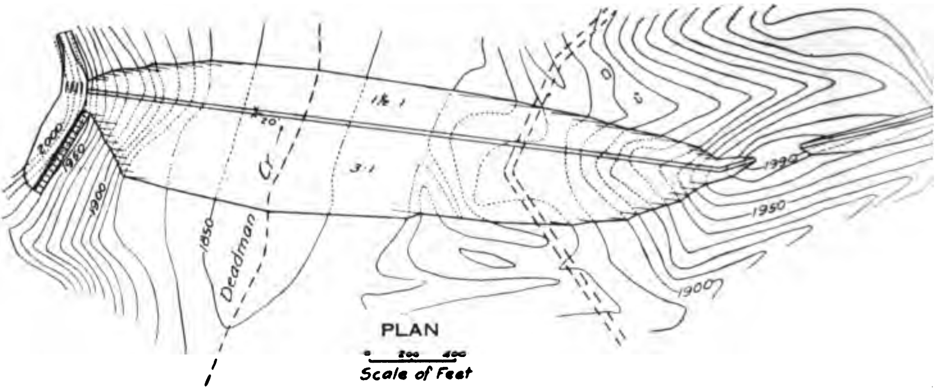
COST OF DEADMAN CREEK DAM. (Fig. 18.)

ITEM	Unit	Quantity	Unit Cost	Cost
Overflow rights	Acre	2,205	$50.00	$110,250
Clearing	Acre	1,000	75.00	75,000
Earth excavation, stripping	Cu. Yd.	115,776	.30	34,733
Earth excavation, sealing trench	Cu. Yd.	15,170	.50	7,585
Steel sheet piling	Lb.	4,396,000	.0575	252,770
Concrete core wall	Cu. Yd.	390	19.00	7,410
Rock fill, from tunnel excavation	Cu. Yd.	1,223,809	.50	611,905
Rock fill, borrow	Cu. Yd.	1,235,557	.90	1,112,001
Preparation of rock face	Sq. Yd.	126,829	.30	38,049
Earth fill	Cu. Yd.	1,056,560	.50	528,280
Earth blanket	Cu. Yd.	342,033	.50	171,017
Hand placed rip rap	Cu. Yd.	67,867	3.00	203,601
Outlet conduit				16,300
Outlet gates				303,720
Reinforced concrete	Cu. Yd.	3,349	19.00	63,631
Concrete roadway	Sq. Yd.	8,220	2.25	18,495
Engineering				90,000
				$3,644,747
Contingencies				160,000
Total cost of Deadman Creek dam				$3,804,747



DEEP CREEK DAM
COLUMBIA BASIN PROJECT
STATE OF WASHINGTON
1920

FIG. 17.



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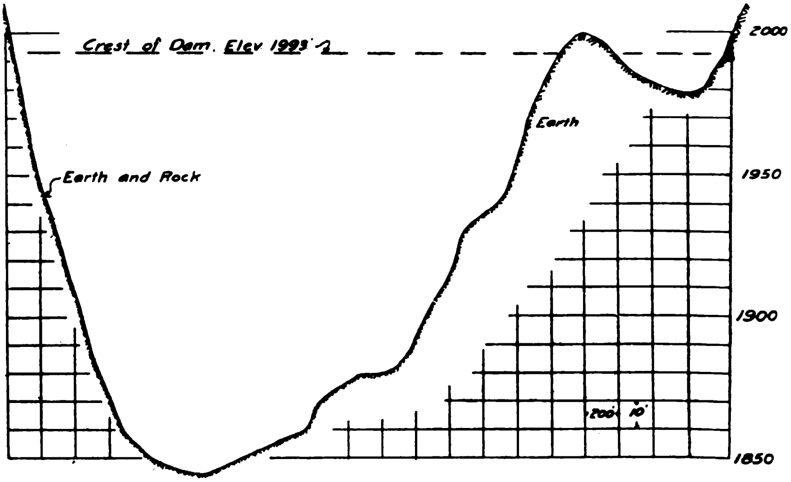

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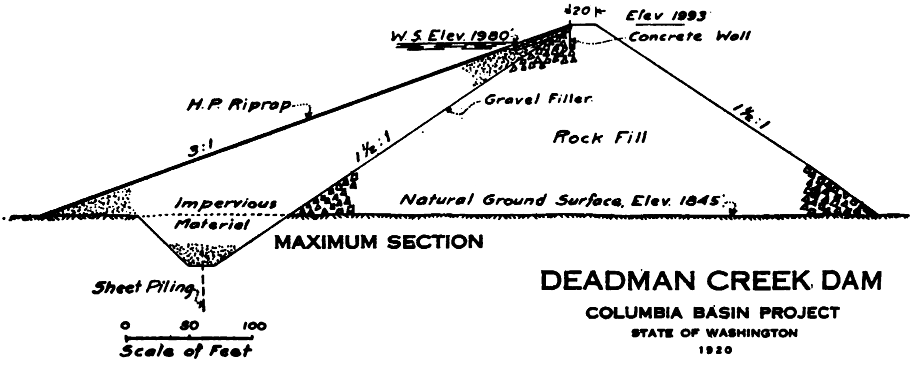
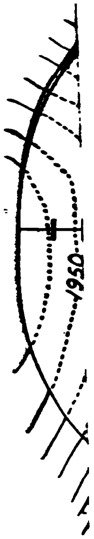


MAXIMUM SECTION

DEADMAN CREEK DAM
COLUMBIA BASIN PROJECT
STATE OF WASHINGTON
1920

FIG. 18.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Latah Creek Dam. At Latah Creek a dam will create a lake eight miles in length and 120 feet maximum depth. Test holes were drilled at the preferable site and a number of different dam designs were made to fit the conditions. Since no rock bottom was found within 100 feet of the surface, it is planned to drive a diaphragm of interlocking steel sheet piling to a depth of 100 feet across the valley bottom and if necessary on the hillsides. Owing to the very porous nature of the large deposits of stream gravel that filled the original Latah Creek Valley, it will be necessary to blanket the valley floor with impervious material both below and above the dam and to carry this blanket up the sides of the valley to the water surface and for some distance up-stream. Large amounts of rock from the Manito tunnel and gravel from the canal excavation across the Spokane Valley will be available for the dam. The accompanying plate and estimate state the technical details.

Table No. 16.

COST OF LATAH CREEK DAM. ((Fig. 19.)

ITEM	Unit	Quantity	Unit Cost	Cost
Overflow rights and road changes	Acre	1,603	....	$376,050
Earth excavation, stripping	Cu. Yd.	68,696	$0.30	20,609
Sealing foundation	....	....	....	317,670
Rock fill from tunnel material	Cu. Yd.	674,275	.25	168,569
Rock fill from borrow	Cu. Yd.	558,176	.90	502,358
Preparation of rock face	Sq. Yd.	70,513	.30	21,154
Earth fill	Cu. Yd.	546,407	.30	163,922
Stripping for earth blanket	Cu. Yd.	26,480	.30	7,944
Earth blanket	Cu. Yd.	79,445	.50	39,723
Hand placed rip rap	Cu. Yd.	79,389	3.00	238,167
Spillway	....	....	....	41,814
Reinforced concrete	Cu. Yd.	1,621	19.00	30,799
Outlet conduit	....	....	....	16,300
Outlet gates	....	....	....	303,720
Concrete roadway	Sq. Yd.	3,980	2.25	8,955
Engineering	....	....	....	80,000
				$2,337,754
Contingencies				150,000
Total cost of Latah Creek dam				$2,487,754

Rock Lake Dam. A natural rock barrier exists around Rock Lake. At the outlet end of the lake this barrier is low. By building a low rock filled dam along the top and providing a concrete spillway near the present stream channel, the lake will be raised 74 feet. This will flood Rock Creek between Rock and Bonnie lakes, making a lake with the water surface at 1,800 feet elevation. No direct storage will be provided in this lake as the water surface in the outlet canal will be at the same elevation.

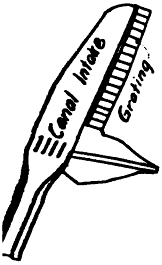
At the southeast end of Rock Lake, the Chicago, Milwaukee & St. Paul Railroad has a large fill across a depression. It is proposed to use this fill as the outer toe of the higher fill which will be a part of the Rock Lake dam. This will increase the security of the railroad line, protect the present fill against all stages of water in the lake and at the same time largely decrease the quantity of material required in that portion of the main dam.

The accompanying sketch illustrates this plan.

Table No. 17.

COST OF ROCK LAKE DAM. (Fig. 20.)

ITEM	Unit	Quantity	Unit Cost	Cost
Overflow rights	Acre	600	$50.00	$30,000
Solid rock excavation for cutoff wall	Cu. Yd.	1,600	5.00	8,000
Wet earth excavation for cutoff wall	Cu. Yd.	1,400	2.00	2,800
Cutoff wall, plain concrete	Cu. Yd.	3,000	12.00	36,000
Rock fill from canal material	Cu. Yd.	681,000	.50	340,500
Rock fill from borrow	Cu. Yd.	914,810	.90	823,329
Preparation for concrete facing	Sq. Yd.	90,630	.30	27,189
Concrete facing, light reinforcement	Cu. Yd.	26,000	18.00	468,000
Solid rock excavation for wasteway	Cu. Yd.	1,000	1.00	1,000
Cofferdam and pumping	....	....	....	5,000
Concrete, light reinforced, wasteway piers	Cu. Yd.	122	20.00	2,440
Concrete, light reinforced, wasteway floor	Cu. Yd.	75	18.00	1,350
Steel gates for wasteway	No.	4	400.00	1,600
Outlet conduit	....	....	....	11,300
Outlet gates	....	....	....	303,720
Drainage tunnel under railway	Lin. Ft.	270	10.00	2,700
Excavation highway crossing	Cu. Yd.	1,300	3.00	3,900
Structural steel highway bridges	Lb.	48,980	.09	4,408
Concrete highway bridge	Cu. Yd.	560	15.00	8,400
Concrete, heavy reinforced, highway bridge	Cu. Yd.	31	30.00	930
Solid rock excavation, retaining wall	Cu. Yd.	2,670	1.50	4,005
Concrete retaining wall, heavy reinf	Cu. Yd.	4,000	28.00	112,000
Concrete roadway	Sq. Yd.	8,400	2.25	18,900
Engineering	....	....	....	90,000
				$2,307,471
Contingencies				100,000
Total cost of Rock Lake dam				$2,407,471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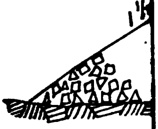
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McCall Dam. A small rock fill is required at a point between the Patterson tunnel and the canal crossing on the Spokane, Portland & Seattle Railroad. This is designed as a rock fill and will create an artificial lake, eliminating a piece of difficult canal construction. A portion of the fill will be material from the first bore of the Patterson tunnel. All of the spoil from this bore and its east approach may be placed in this dam.

Table No. 18.

COST OF FOUR MINOR DAMS.

McCall Dam and Dike.

ITEM	Unit	Quantity	Unit Cost	Cost
Overflow rights	Acre	300	$15.00	$4,500
Earth excavation, stripping	Cu. Yd.	40,631	.50	20,316
Rock fill from tunnel excavation	Cu. Yd.	178,201	.30	53,460
Rock fill from borrow	Cu. Yd.	161,028	1.00	161,028
Preparation for facing	Sq. Yd.	24,384	.30	7,315
Reinforced concrete facing	Cu. Yd.	6,321	18.00	113,778
Plain concrete in spillway	Cu. Yd.	97	15.00	1,455
Outlet conduit				7,550
Engineering				7,000
				$376,402
Contingencies				25,000
Total cost of McCall dam and dike				$401,402

Dam at South and Central Diversion.

ITEM	Unit	Quantity	Unit Cost	Cost
Overflow rights	Acre	100	$23.50	$2,350
Earth excavation, stripping	Cu. Yd.	21,260	.25	5,315
Rock fill from tunnel	Cu. Yd.	123,270	.45	55,472
Preparation of rock face	Sq. Yd.	13,121	.30	3,936
Earth fill	Cu. Yd.	53,907	.35	18,867
Hand placed rip rap	Cu. Yd.	8,747	3.45	30,177
Outlet conduit				8,800
Outlet gates				42,880
Engineering				4,100
				$171,900
Contingencies				8,200
Total cost of dam				$180,100

Dam, Providence Main "CD."

ITEM	Unit	Quantity	Unit Cost	Cost
Reservoir right of way	Acre	50	$30.00	$1,500
Rock fill from tunnel	Cu. Yd.	51,955	.30	15,587
Earth fill	Cu. Yd.	19,776	.35	6,922
Hand placed rip rap	Cu. Yd.	4,672	3.25	15,184
Excavation	Cu. Yd.	8,911	.25	2,228
Preparation of face	Sq. Yd.	6,933	.30	2,080
Outlet conduit				7,550
Engineering				1,000
				$52,051
Contingencies				2,000
Total cost of dam				$54,051

Dam, Eureka Main "SJ."

ITEM	Unit	Quantity	Unit Cost	Cost
Right of way	Acre	35	$30.00	$1,050
Earth fill	Cu. Yd.	75,000	.50	37,500
Hand placed rip rap	Cu. Yd.	4,700	3.00	14,100
Engineering				500
				$53,150
Contingencies				5,000
Total cost of dam				$58,150

Table No. 19 — RECAPITULATION OF DAMS.

LOCATION	TYPE	Length of Crest	Crest Height Above Foundation	Maximum Depth of Water	Cubic Yards in Structure	Cost
		Feet	Feet	Feet		
Flathead	Concrete with stoney gates	580	60	53	10,587	$553,933
Albany Falls	Concrete with stoney gates	1,025	46	31	13,600	766,368
Camden	Rock and earth fill	1,100	148	135	1,219,612	1,437,788
Dry Creek	Rock and earth fill	3,140	122	109	1,113,101	1,149,905
Deep Creek	Rock and earth fill	778	95	82	461,166	731,807
Deadman Creek	Rock and earth fill	3,800	148	135	3,929,565	3,804,747
Latah Creek	Rock and earth fill	1,960	133	120	1,961,978	2,487,754
Rock Lake	Rock fill	6,800	85	72	1,629,038	2,407,471
McCall	Rock fill	2,200	102	92	345,647	401,402
Dragoon Lake	Rock fill	450	28	23	11,393	17,659
Supply Canal Totals					10,695,687	$13,758,826
South Main Diversion	Rock and earth fill	1,200	64	54	185,924	180,100
Providence Main	Rock and earth fill	800	51	41	76,403	54,051
Eureka Main	Earth fill	750	60	50	79,700	58,150
Totals for all dams					11,037,714	$14,051,127

The dams proposed in connection with waste water control and possible secondary storage would be at the following named sites: First Coulee, Rattlesnake Canyon, Smith Canyon, Black Rock Coulee, and Old Maid Coulee.

Aneroid and hand level surveys, with United States Geological Survey topographic sheets covering some of the sites, supplied the data used.

Each location appears suitable for a rock fill supporting an earth blanket with concrete spillway in rock. A reconnaissance was made of the area to be flooded and of the right of way for wasteway. The cost estimates are based on approximate quantities only. Since the cost of this proposed secondary storage is not included in the estimated costs of the project at this time, no error is introduced by the lack of detailed studies. The secondary storage would not be developed in any event before the starting of construction of the second half of the project and this will afford ample time for making exact surveys and estimates and a determination of whether the cost of such storage is justified by the saving in cost on the main canals.

Table No. 20 — SECONDARY STORAGE RESERVOIRS.

LOCATION	Maximum Area Flooded	Capacity in Acre-Feet	Length of Dam	Height of Dam	Crest Elevation Above Sea-Level	Cubic Yards in Dam	Estimated Cost	Cost per Acre-Foot
	Acres		Feet	Feet				
First Coulee	1,177	68,840	2,430	150	1,532	2,653,000	$2,548,756	$37.02
Black Rock Coulee	1,441	51,220	5,800	70	1,330	1,685,000	1,547,100	30.20
Rattlesnake Canyon	2,960	181,250	5,400	170	1,275	3,375,000	3,059,200	16.88
Smith Canyon	2,920	128,710	4,200	150	1,040	2,284,000	2,084,500	16.20
Old Maid, Upper	1,467	54,260	6,000	120	1,050	2,170,000	1,983,750	36.56
Old Maid, Lower	1,110	56,510	3,500	135	900	2,188,000	1,944,100	34.40
Wynett Canyon	1,800	100,000	1,600	180	1,050	....	....	....

First Coulee Dam. The First Coulee dam is a hydraulic fill of the standard design and presents no unusual features other than its large size. Since this dam is placed on the drainage course above the main canal crossing, an auxiliary canal from the main canal to the rservoir is necessary. This canal will be 10,200 feet long and have a capacity of 4,600 second-feet as it may at times act as a spillway from the main canal and must have the same capacity. The outlet canal from the reservoir will carry 800 second-feet.

The Marcellus branch of the Chicago, Milwaukee & St. Paul Railroad will have to be relocated for 12.28 miles. The new line will be about two miles longer than the present one. These items are included in the estimated cost of $2,549,000 for secondary storage in First Coulee.

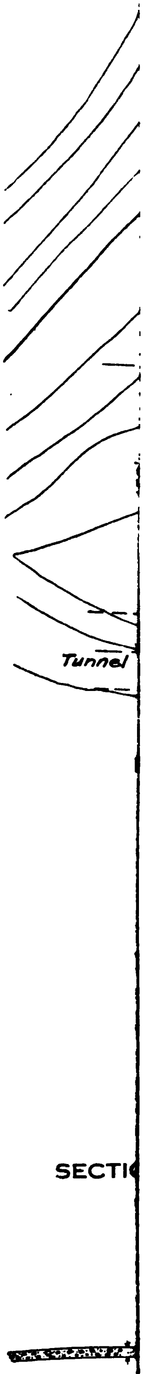
(2) *Head and Waste Gates.* The larger sizes of headgates will be of the Stoney type. Since a large number of gate installations will be required at the dams and points of diversion for distributing canals, more detailed study was given to types and designs of gates than to any other structure.

The Stoney gate was adopted because of several reasons: (1) Greater reliability of operation. (2) Less subject to damage from floating debris or other causes. (3) The design is subject to more positive strain analysis. (4) The workmanship need not be as skilled to produce and maintain a satisfactory gate.

On the smaller canals where not more than two gates are required for the control, the Taintor radial gate may be used. At all places where several gates and piers are necessary, the Stoney type has been adopted.

The diversion gates at Albany Falls will be placed in two groups 150 feet apart. This is to give separate control of the flow in each of the twin tunnels, which will be 150 feet center to center. The tunnels will be reached by separate channels from the corresponding group of gates. Each group will contain seven gates whose sill elevation will be at 2,042, which is 13.5 feet higher than the tunnel invert. This arrangement places the gate sills two feet higher than the sills on the diversion dam and is expected to force sand moving along the river bed over the dam instead of through the gates. Each waterway through the gates will be 10 by 12 feet. The piers and curtain wall above the headgates will be carried to elevation 2,078, well above the elevation of the highest known flood.

Pend Oreille River during flood carries much drift-wood and at all times of the year carries logs and ties escaping



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from the mill booms above. To prevent entrance of this material into the canal, heavy steel rail gratings will be placed across the diversion channel about 500 feet above the head gates. These gratings will extend from low to high water elevations and be so arranged as to permit easy clearing in case of accumulation of debris.

All gate controls will be by electric motor-driven hoisting apparatus, with gasoline engine and hand power auxiliary control. The larger gates will be of concrete-protected steel, counter-balanced, so that a relatively small amount of power will be required for their operation.

Emergency gates may be placed at the entrance to the tunnels at Albany Falls, to be used in the remote possibility of an accident to the headgates. Such gates would close quickly without the aid of power.

At all of the lakes along the canal system, outlet gates will be erected for two purposes: First, to effect a temporary regulation of the flow in the canal below, and second, to create storage in the lake by completely closing the gates and retaining in the lake water reaching it from the next higher section of canal. This is fully discussed in the appendices on "Secondary Storage" and "Drainage and Wasteways."

At each junction of canals, suitable gates will be placed to regulate the flow into each branch. These structures will embrace the usual varieties of gate, each being chosen to fit the volume and other controlling characteristics at the particular site. Only tentative designs were prepared, as the regulation desirable in each place can only be determined after a much more comprehensive study of the distribution system, and such study is possible only after the preparation of detailed topographic sheets of the entire project.

The design and cost of the canal headgates at Albany Falls are typical of all those estimated.

Table No. 21.
SUPPLY CANAL HEADGATES AT ALBANY FALLS. (Fig. 21.)

ITEM	Unit	Quantity	Unit Cost	Cost
Excavation, includes east transition, Newport tunnel	Cu. Yd.	144,250	$1.00	$144,250
Concrete without reinforcement	Cu. Yd.	796	15.00	11,940
Concrete, light reinforcement	Cu. Yd.	6,450	19.00	122,550
Concrete, heavy reinforcement	Cu. Yd.	553	27.00	14,931
Piling	Lin. Ft.	7,100	.60	4,260
Grating, steel rails	Ton	270	70.00	18,900
Hand placed rip rap	Cu. Yd.	2,500	3.00	7,500
Structural steel in gates	Lb.	205,100	.10	20,510
Operating mechanism				56,000
Engineering				15,000
				$415,841
Contingencies				25,000
Total cost of Albany Falls headgates				$440,841

(3) *Canals.* In making the estimates of cost of the large canals, seven standard sections were used. On the distribution lines, one general type was used. The accompanying sketches and tables of hydraulic properties show the controlling features of each section and are self-explanatory.

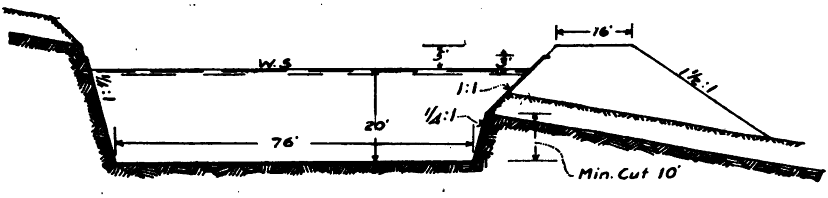

FIG. 22. TYPE 1.

Type No. 1 is used in solid rock, through flat or gently sloping country.

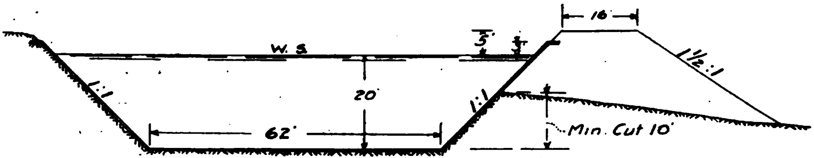

FIG. 23. TYPE 2.

Type No. 2 is used in other than solid rock, through flat or gently sloping country.

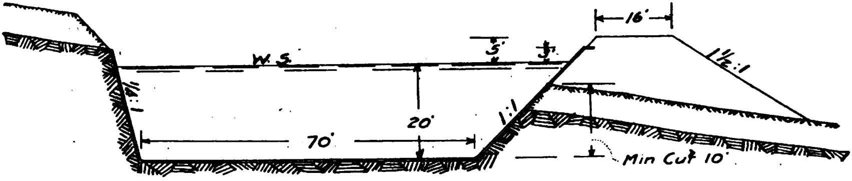

FIG. 24. TYPE 3.

Type No. 3 is used where uphill side is rock and lower side is loose material, through gently sloping country.

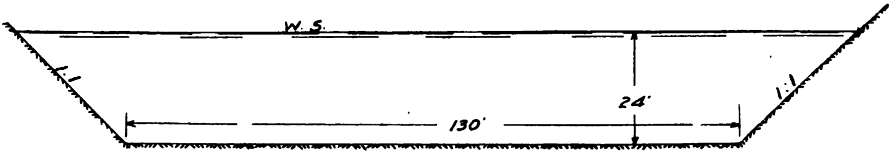

FIG. 25. TYPE 4.

Type No. 4 is used only where channel of Little Spokane River is enlarged.

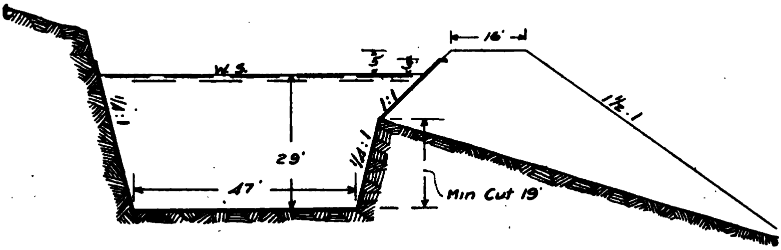

FIG. 26. TYPE 5.

Typo No. 5 is used in solid rock, through broken and steep country.

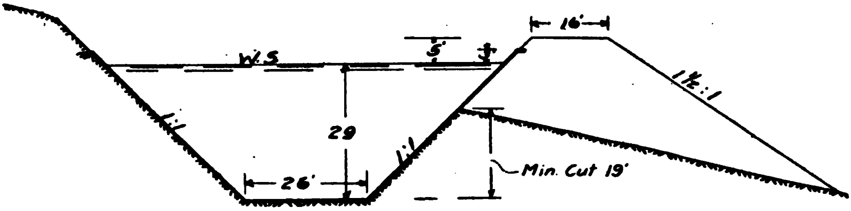

FIG. 27. TYPE 6.

Type No. 6 is used in material other than solid rock, through broken and steep country.

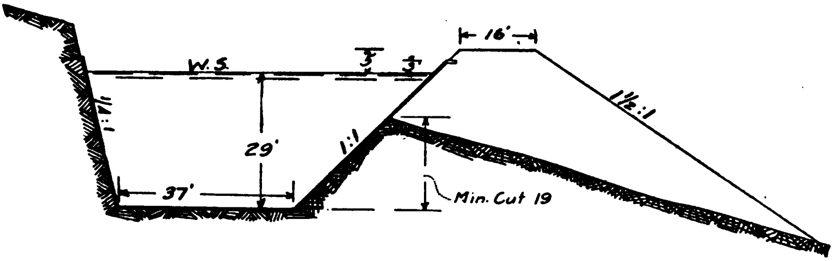

FIG. 28. TYPE 7.

Type No. 7 is used where uphill side is in solid rock, and lower side in other material, through broken and steep country.

Table No. 22.

HYDRAULIC PROPERTIES, SUPPLY CANAL SECTIONS.

Type	1	2	3	4	5	6	7
Bottom width in feet	76	62	70	130	47	26	37
Depth in feet	20	20	20	24	29	29	29
Hydraulic radius in feet	13.7	13.83	13.89	18.7	14.5	14.76	14.8
Area of flow section, in square feet	1,657.5	1,640	1,650	3,696	1,611	1,595	1,598
Wet perimeter in feet	121	118.6	118.8	198	111	108.1	108
Kutter's "n"	.014	.014	.014	.0225	.014	.014	.014
Slope	.000475	.000475	.000475	.00014	.000475	.000475	.000475
Fall in feet per mile	2.51	2.51	2.51	0.75	2.51	2.51	2.51
Velocity in feet per second	12.1	12.15	12.18	5.4	12.5	12.63	12.65
Quantity in cubic feet per second	20,040	19,920	20,100	20,000	20,134	20,145	20,214

The discussion of engineering studies in Chapter 5 outlines the reasons for adopting the several sections used. In the absence of engineering precedent for carrying such a volume of water—20,000 cubic feet per second—in canals elevated at some places several hundred feet above the valley floor, certain safety precautions were arbitrarily adopted. Further study of the plans may lead to modifications permitting less expensive construction. When designing the several sections of the main supply canal, the rule was followed that the elevation of water surface above the original solid ground surface at the outer bank must not exceed 10 feet. For the sections based on the semi-hexagonal type, this required a minimum cut of 19 feet at the outer edge and on those sections for which the ratio of bottom width to water depth exceeds three to one, the minimum cut becomes 10 feet. Along most of the hillsides, this section results in an excess of excavated material over fill requirements. The excess was used to widen the fill, giving a more substantial bank than would have been acceptable if the cut and fill were just balanced.

Sections were figured for an average velocity of 12½ feet per second, using Kutter's coefficient of friction $n = 0.014$. This figure, or slightly less, represents the coefficient of friction which has been adopted for or found to exist in several of the recently designed or constructed large concrete-lined aqueducts.* The work of the various experimenters and engineers who have studied Kutter's formula, indicates that as volume of flow is increased, a lower coefficient of friction is applicable than exists in small sections of the same character of lining. The Columbia Basin main supply canal will carry a larger volume of water than any concrete-lined aqueduct for which the friction factors have been determined. On that canal, n will undoubtedly be less than 0.014 but the latter figure is the lowest shown by authoritative experiments on smaller canals and it has been adopted here.

Computations indicate that at a certain depth, when the canals are carrying a small proportion of their maximum capacity, the critical velocity is reached; that is, the depth equals twice the head creating the existing velocity of flow. At this point the hydraulic jump or surge may occur in the flow, but since the free-board then existing will be four to five times greater than the highest possible surge, this is not a serious matter. At depths exceeding one-fourth of the maximum depth, the velocity exceeds the critical flow and such surges cannot develop.

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* United States Reclamation Service. Los Angeles Aqueduct. Hetch Hetchy Aqueduct.

The high velocity will result in the development of a standing wave or surge should obstructions exist in the canal or irregularities be permitted in the alignment of the banks. The size of the canal precludes sharp curves being used and most careful attention must be given to the design and construction of all transitions between one section and another, approaches and outlets to structures, etc. The height of lined free-board has been made equal to the velocity head in feet plus one-half foot. From three to five feet of earth bank will remain above the concrete lining, insuring ample free-board for protection against any possible development of wave action.

The distribution mains and laterals are practically all in open country. This permits of the economical construction of a wider canal section than the hexagonal section. It also permits steeper gradients for most of the canals since they follow the ridges and must be governed by the supporting ground. The steeper gradient calls for the wide section of canal to increase the wetted perimeter and prevent the velocities becoming excessive. The ratio of bottom width to water depth averages three to one. The water cross-section varies from eight square feet for the 100 second-feet capacity to 1,650 square feet for 20,000 second-feet capacity.

In the areas where each foot of grade saved means additional acreage can be irrigated, a slope of one foot to the mile has been used. Along some of the ridges small canals have been carried on a slope as steep as 100 feet per mile. Nearly every combination of slope, cross-section, and capacity has been encountered at some point in the distribution.

The distribution system has been designed to deliver to any area in any one month 20 per cent of the total water for the season. An additional requirement is that one month's flow must deliver not less than six inches depth of water over the area irrigated, even on the high duty lands where 20 per cent of the total would be under six inches. This in effect places the same distribution system on the land having the duty of 18 or 24 inches as on the land requiring 30 inches. The relative flows and duties are shown in the accompanying table.

Table No. 23.

CAPACITY OF LATERALS—WATER DUTIES AND MONTHLY QUANTITIES.

Seasonal Duty on Ground	Seasonal Flow in Canal, in Acre-Inches Per Acre	Duty on Ground During Maximum Month 20%, but Minimum Never Less Than 6″ in One Month	Acre-Inches per Acre Required in Canal During Maximum Month to Satisfy Preceding Column, at 15% Loss
18″	21.18	6.0″	7.06
24″	28.24	6.0″	7.06
30″	35.29	6.0″	7.06
33″	38.82	6.6″	7.76
36″	42.35	7.2″	8.47
48″	56.47	9.6″	11.29
50″	58.82	10.0″	11.76
60″	70.59	12.0″	14.12

The distribution system has been located and the structures designed for the various sizes down to 100 second-feet capacity. For the average duty of water, 100 second-feet will supply 10,000 acres. Fifteen dollars per acre is the assumed cost of distribution below 100 second-feet capacity. This figure covers all charges, except for farm laterals and land preparation; and approximates the costs of similar installations, under present prices, in the Central Washington, Oregon and Idaho districts.

The larger laterals have been located either by surveys or by projection on topographic sheets. A cross-section of canal has been adopted to fit the flow required, grade available, and materials to be excavated on the several lines. The side slopes were ascertained and the quantities calculated.

The considerations leading to the adoption of concrete lining are as follows: First, such lining permits the use of higher velocities than could be allowed in earth canals; second, the higher velocity permits the use of smaller cross-sections with less expense for excavation; third, a smaller cross-section of canal is practical to construct on hillsides where a larger canal might be impossible; fourth, lining reduces the seepage losses to a negligible amount; fifth, the maintenance of a lined canal is much less than that of an unlined canal; sixth, the volume of water in the canal is comparatively small and easier to dispose of when shutting down; seventh, concrete lining permits the use of a section with highly desirable hydraulic properties and maintains the banks so as to retain those qualities; eighth, concrete lining prohibits the perforation of banks by burrowing animals, the erosion of the banks by wave action in the canal and the growth of brush and weeds where they will interfere with the flow of the water.

Concrete lining will be placed in the canals in accordance with the following table:

Table No. 24 — CONCRETE LININGS.

In loose rock and earth; concrete mixture 1:2:4.

Depth of Water in Feet	Average Thickness in Inches	Depth of Water in Feet	Average Thickness in Inches
29	8	14	5½
19 and 20	7½	11 and 12	5
17 and 18	7	9 and 10	4½
16	6½	6 to 8	4
15	6	4 and 5	3

In solid rock sections, the average thickness is six inches, with no reinforcing. All linings are tapered from bottom to top, the above being average thicknesses. Reinforcement has been estimated, a sufficient proportion of steel being used to withstand temperature strains and to protect the concrete lining against sudden collapse in case of erosion of the supporting bank.

For placing the concrete lining special equipment may be used, with portable steel forms, traveling on tracks in the bottom of the canal, and carrying the mixing and placing equipment with it as it moves from section to section of the canal. This will eliminate a large part of the usual labor and achieve uniform results and low costs.

The total surface area of the concrete lining approximates 23 million square yards. If we assume that seepage loss will take place through this lining, at the rate of one inch in depth, per 24 hours, over the wetted surface, and assume that the canal is filled to the top of the lining, the loss will be less than two-tenths of one per cent of the volume flowing. This figure is negligible. The loss through the construction joints can be reduced to a very small figure. Five per cent of the diverted flow has been assumed to cover the foregoing losses and the waste which accompanies regulation.

The estimated costs of excavating the several classes of material in the canals are based on a study of the methods and costs of similar work being carried on at the present time. The unit costs contain liberal allowances for contingencies and it is believed that the work can be done within these estimates, even under more unfavorable labor conditions than at present.

It is recognized that when construction begins on the Columbia Basin Project, labor conditions may be different and unit costs may vary widely from those stated. The rapid development of labor-saving machinery has largely offset the increasing inadequacy and inefficiency of labor. It is anticipated that the substitution of machines for men will become more profitable each year.

The large amount of materials to be handled from the Columbia Basin canals will justify the installation of the largest size and most economical forms of excavating equipment. Along the upper portions of the canal self-contained and self-propelled dragline excavators will find a field for highly efficient work. Electric power is available throughout a large portion of the district and the service can be easily extended along all the canal lines. With this cheap and flexible power at hand, electric-driven excavators can be economically used on all but the smallest sizes of laterals and very low unit costs will result.

There will be no maintenance of large camps for horses and mules and their attendant problems of water and forage in a desert country. Large numbers of unskilled laborers will not be necessary. The skilled mechanics employed on the high powered, large capacity excavators are intelligent, highly paid, and take an interest in the operation of machinery under their charge. This largely eliminates delays, strikes, camp troubles and the other difficulties attendant upon the old time construction jobs.

The following tables show a summary of the estimates on the main supply canal, and a recapitulation of the canal estimates on the entire supply and distributing systems.

Table No. 25.

CANALIZATION OF LITTLE SPOKANE RIVER FROM NEWPORT TUNNEL TO CHAIN LAKES.

ITEM	Unit	Quantity	Unit Cost	Cost
Right of way	Acre	204	$30.00	$6,270
Clearing	Acre	30	75.00	2,250
Excavation, earth	Cu. Yd.	8,558,850	.20	1,711,770
Excavation, solid rock	Cu. Yd.	360,000	1.25	450,000
Steel in road crossings	Lb.	221,600	.09	19,944
Concrete in road crossing	Cu. Yd.	60	15.00	900
Engineering				25,000
				$2,216,134
Contingencies				175,000
Total cost of channel enlargement				$2,391,134

Table No. 26.

SUPPLY CANAL, CAMDEN DAM TO HILLCREST.

ITEM	Unit	Quantity	Unit Cost	Cost
Right of way*	Acre	1,686	....	$265,680
Clearing	Acre	534	$50.00	26,700
Excavation, earth	Cu. Yd.	8,504,920	.20	1,700,984
Excavation, loose rock	Cu. Yd.	2,267,320	.60	1,360,392
Excavation, solid rock	Cu. Yd.	5,788,400	1.20	6,946,080
Excavation, solid rock (deepening Rock Creek)	Cu. Yd.	185,000	1.25	168,750
Overhaul †	Yd.-Mi.	11,156,300	.05	557,815
Canal lining, concrete	Cu. Yd.	735,850	16.00	11,773,600
Reinforcing, steel	Lb.	12,886,000	.06	773,160
Railroad crossings, concrete	Cu. Yd.	1,860	15.00	27,900
Road crossings, steel	Lb.	1,474,040	.09	132,664
Engineering				240,000
				$23,973,725
Contingencies				1,378,000
Total cost				$25,351,725

* Includes overflow rights, buildings removed, etc.

† The canal in crossing the Spokane Valley is all in deep cut through valuable land. The excess material will probably be hauled 6½ miles through Manito Tunnel to Latah Dam.

Table No. 27 — RECAPITULATION OF CANALS.

LOCATION	Length in Feet	Slope in Feet Per 1,000 Feet	Velocity in Feet Per Second	Capacity Second-Feet		Excavation Cu. Yds.	Concrete Lining	Cost
				From	To			
MAIN SUPPLY CANAL—								
Newport Tunnel to Chain Lakes	30,334	0.14	5.4	20,000	20,000	8,918,850	....	$2,391,134
Camden Dam to Hillcrest	273,178	0.475	12.2	20,000	20,000	16,695,640	735,850	25,351,725
NORTH DIVISION—								
North Main	101,694	0.475	9.2 to 9.9	6,850	4,500	8,740,831	506,218	
Quincy Main	256,950	0.40 to 0.475	5.4 to 9.15	4,250	1,990	2,861,713	229,537	
Babcock Main	273,300	0.19 to 5.59	3.7 to 11.7	1,990	235	1,705,000	170,561	
Laterals	1,096,000	0.19 to 11.93	2.5 to 12.5	880	100	2,460,100	220,649	
Total, North Division, Canals only								29,461,667
CENTRAL DIVISION—								
Providence Main	90,350	0.80	11.9 to 12.2	7,020	6,440	2,451,710	153,023	
Shano Main	99,000	0.50 to 1.10	10.3 to 12.2	5,800	3,700	1,236,230	78,247	
Saddle Mountain Main	256,483	0.40 to 2.00	3.3 to 12.1	1,960	100	1,776,501	368,367	
West Pasco Main	211,770	0.20 to 2.50	4.4 to 12.5	1,605	100	1,061,292	89,570	
Laterals	829,700	0.20 to 15.00	2.5 to 13.0	1,680	100	1,501,647	172,220	
Total, Central Division, Canals only								17,167,575
SOUTH DIVISION—								
South Main	68,150	0.60	12.0	12,100	12,100	2,769,519	130,619	
Lateral from Hillcrest	123,670	0.20 to 0.40	2.5 to 5.0	588	100	408,106	30,296	
Snake River Main	245,900	0.915to 11.00	12.5	4,850	100	1,950,038	159,037	
East Pasco Main	355,000	0.20 to 8.14	2.5 to 12.5	1,145	100	774,574	84,106	
Eureka Main	77,088	0.47 to 2.00	6.8 to 11.7	1,700	1,455	554,963	42,241	
Snake River Main Laterals	254,300	0.92 to 11.00	12.5	4,400	100	439,529	50,438	
Eureka Main Laterals	293,516	0.55 to 7.35	4.4 to 11.7	750	100	453,711	56,906	
Lateral "M1"	36,000	0.20	2.7 to 2.5	136	100	66,620	7,108	
Total, South Division, Canals only								12,239,162
Total all canals	4,972,383 ft. = 941.7 miles					56,826,624 cu. yds.	3,284,994 cu. yds.	$86,611,263

(4) *Tunnels.* The standard horseshoe design was adopted for all tunnels, the section and slope being varied to suit each locality. The tunnels will be concrete-lined and when operated at full capacity will have a clearance of approximately one-seventh the vertical dimension. The following figures show the section dimensions, quantities, and hydraulic properties of the larger tunnels:

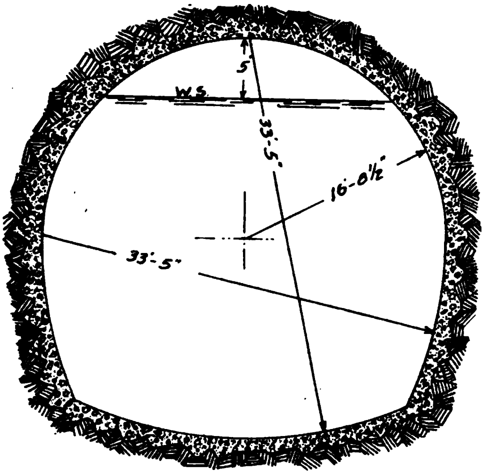


FIG. 29. TYPE A.

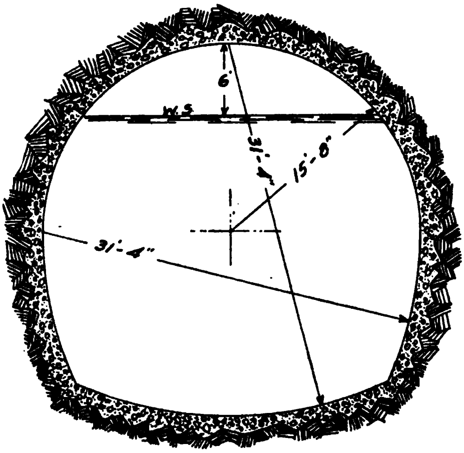


FIG. 30. TYPE B.

Table No. 28.

DIMENSIONS AND PROPERTIES OF TUNNELS.

	Type A	Type B
Diameter	33 ft. 5 in.	31 ft. 4 in.
Excavation per linear foot	38.53 cu.yd.	34.14 cu.yd.
Minimum thickness concrete lining	12 in.	12 in.
Average thickness concrete lining	17.5 in.	16.5 in.
Concrete lining per linear foot.	5.71 cu.yd.	5.15 cu.yd.
Hydraulic radius	10.2 ft.	9.6 ft.
Slope	.00075	.00114
Fall per mile.	3.96 ft.	6.02 ft.
Velocity per second	12 ft.	14.2 ft.
Capacity of single bore in second-feet	9,977	10,089

Along the main supply canal, two parallel bores are required to handle 20,000 second-feet of water. This is because it is considered not feasible to construct a single bore of large enough capacity to carry the entire flow. Such a bore would require a roof span exceeding 45 feet, would increase the difficulty at the transition because of the excessive sub-grading which would be required, and would necessitate the maximum expenditure early in the construction period. Two bores reduce the dimensions to within reasonable limits, and permit the cost of the second bore to be postponed until the increasing demand as the project develops necessitates the full water supply.

Studies were made on the horseshoe type and a semi-rectangular type, and of both types on various slopes. The shape and slopes adopted are the economical mean of the various possibilities. A variation in the proportionate unit costs, as between earth and rock excavation and concrete linings, may make it feasible to put more or less gradient into the tunnels, making a corresponding change in the gradient of the canals, and in the excavated area of both. This can only be determined by the unit costs prevailing at the time construction is authorized.

The coefficient of friction adopted for the lined tunnels is $n=0.015$. While the value 0.014 was adopted for the canal linings and undoubtedly can be equaled in the tunnels, the larger figure was used in the tunnels, because of, first, the practical impossibility of enlarging the tunnels should the flow prove insufficient; and second, the difficulty of cleaning the tunnel linings should growths of any kind increase the roughness. Should the frictional resistance in the tunnels be less than designed for, the effect will be to lower the depth of water running. This will increase the clearance, which is desirable.

The construction plan and estimated costs are based upon driving one bore of each tunnel and putting this to use within a period of four years. To the first bore is charged the construction of standard railway from the existing roads to the tunnel portals, erection of camps, purchase and installation of all machinery and equipment, and the excavating and lining of the bore. Immediately upon completion of the first bore, the second will be driven but has only been charged with excavation, lining, and maintenance and upkeep of equipment, since the railway, camp, and machinery were paid for by the earlier bore. In the estimates following, this difference appears in the lower unit cost of excavation of the second bore.

The Bonnie Lake tunnel will be driven from two portals and three shafts (the latter 6 feet by 18 feet and 550 feet average depth), making eight working faces. Pioneer headings totaling 40,000 feet will speed up the driving of the first bore, and will be so located that they will become a part of the heading for the second bore.

Electric power will be available at each portal. In all the tunnels power shovels will load into standard gauge railway dump cars. From several of the tunnels the excavated material will go into adjacent rock fill dams.

Table No. 29 — COST OF TUNNELS.

TUNNEL	RIGHT OF WAY			EXCAVATION FIRST BORE ‡		
	Acres	Unit Cost	Amount	Cubic Yards	Unit Cost	Amount
Newport	251	$30.00	$7,530	1,072,714	$5.46	$5,857,018
Milan	84	40.00	3,360	532,677	5.26	2,801,828
Deep Creek	37	40.00	1,480	229,909	5.26	1,209,321
Deadman Creek	40	40.00	1,600	337,908	5.26	1,777,396
Pleasant Prairie	137	30.00	4,110	641,139	4.99	3,199,284
Manito	71	500.00	35,500	539,420	5.41	2,918,262
Bonnie Lake	360	30.00	10,800	2,934,859	6.03	17,708,750
Patterson	17	30.00	510	142,561	5.26	749,871
McElroy	7	30.00	210	233,618	5.58	1,303,588
Paha	2	30.00	60	56,980	5.58	317,948
Klemmer	16	30.00	480	578,347	5.58	3,227,176
Low Gap	4	30.00	120	77,900	7.76	604,504
Main "CC'	3	30.00	90	71,820	5.82	417,992
Main "CD"	3	30.00	90	79,002	5.82	459,792
Main "CD"	1	30.00	30	82,466	5.82	188,836
South Main	4	30.00	120	146,055	5.33	778,473
Main "SF"	2	30.00	60	48,060	6.55	314,793
Main "SG"	4	30.00	120	89,880	6.55	588,714
Main "SH"	1	30.00	30	14,639	7.27	106,426
Eureka Main "SJ"	1	30.00	30	12,030	8.00	96,240
Eureka Main "SJ"	4	30.00	120	63,184	8.00	505,472
Totals	1,049	....	$66,450	7,935,168	....	$45,131,684

‡ Among other items charged to the first bore, which are not charged to the second bore, are the following—

TUNNEL	Outside Railway	Camp and Equipment	Power Plant	Other Plant	
Newport	$40,000	$100,000	$105,000	$408,000	Probably in wet ground.
Milan, Deep and Deadman	400,000	75,000	123,750	556,994	Same equipment used on all three tunnels.
Pleasant Prairie	105,000	25,000	41,250	276,000	
Manito	125,000	37,500	41,250	255,000	
Bonnie Lake	975,000	262,500	365,000	1,410,050	Includes also pioneer headings, shafts, and crosscuts.

Table No. 29 — COST OF TUNNELS — Continued.

TUNNEL	EXCAVATION SECOND BORE			CONCRETE LINING		
	Cubic Yards	Unit Cost	Amount	Cubic Yards	Unit Cost	Amount
Newport	1,072,714	$4.85	$5,202,668	817,944	$15.00	$4,769,160
Milan	532,677	4.30	2,290,468	157,882	15.00	2,368,230
Deep Creek	229,909	4.30	988,609	68,144	15.00	1,022,160
Deadman Creek	337,908	4.30	1,453,004	100,154	15.00	1,502,310
Pleasant Prairie	641,139	4.32	2,769,720	190,028	15.00	2,850,420
Manito	539,420	4.67	2,519,091	158,880	15.00	2,383,200
Bonnie Lake	2,759,533	3.96	10,915,185	857,578	15.00	12,863,670
Patterson	142,561	4.30	613,012	42,254	15.00	633,810
McElroy	....	....	....	35,670	15.00	535,050
Paha	....	....	....	8,700	15.00	130,500
Klemmer	....	....	....	88,305	15.00	1,324,575
Low Gap	....	....	....	15,200	15.00	228,000
Main "CC"	....	....	....	11,310	15.00	169,650
Main "CD"	....	....	....	12,441	15.00	186,615
Main "OD"	....	....	....	5,278	15.00	79,170
South Main	....	....	....	21,840	15.00	327,600
Main "SF"	....	....	....	7,860	15.00	117,900
Main "SG"	....	....	....	15,000	15.00	225,000
Main "SH"	....	....	....	2,706	15.00	40,590
Eureka Main "SJ"	....	....	....	2,430	15.00	36,450
Eureka Main "SJ"	....	....	....	12,830	15.00	192,450
Totals	6,255,861	....	$26,751,752	2,132,434	....	$32,001,510

Table No. 29 — COST OF TUNNELS — Concluded.

TUNNEL	Transitions	Engineering	Contingencies	Totals
Newport	....	$150,000	$1,657,884	*$18,394,255
Milan	$253,156	80,000	771,368	8,568,410
Deep Creek	253,156	35,000	347,095	3,856,821
Deadman Creek	126,578	50,000	485,929	5,396,817
Pleasant Prairie	253,156	100,000	907,258	10,083,948
Manito	253,156	100,000	953,871	† 10,628,080
Bonnie Lake	....	434,000	4,148,761	46,081,166
Patterson	253,156	23,000	224,985	2,498,344
McElroy	....	20,000	183,864	2,042,712
Paha	....	5,000	44,845	498,353
Klemmer	....	48,000	455,175	5,055,406
Low Gap	....	12,000	83,250	927,874
Main "CC"	....	6,000	58,764	652,496
Main "CD"	....	7,000	64,641	718,138
Main "OD"	....	3,000	26,800	297,836
South Main	....	12,000	110,607	1,228,800
Main "SF"	....	4,500	43,270	480,523
Main "SG"	....	9,500	81,371	904,705
Main "SH"	....	1,500	14,702	163,248
Eureka Main "SJ"	....	1,400	13,269	147,389
Eureka Main "SJ"	....	7,200	69,792	775,034
Totals	$1,392,358	$1,109,100	$10,747,501	$119,400,355

* Includes 1,500 feet of tunnel in earth at $500 per foot, $750,000.

† Includes 2,900 feet of tunnel in earth at $500 per foot, $1,450,000.

Table No. 30 — RECAPITULATION OF TUNNELS.

NAME	Formation	Length Feet	Diameter Ft. In.	Number Bores	Slope Ft. per 1,000	Cu. Yds. Excavation Lin. Ft.	Cu. Yds. Concrete Lining Lin. Ft.	C'pacity Sec. Ft. One Bore	Average Cost per Lin. Ft. One Bore	Total Cost
MAIN SUPPLY—										
Newport	Granite and earth.	28,591	33′ 5″	2	0.75	38.53	5.71	9,971	$321.68	$18,394,255
Milan	Granite	13,825	33′ 5″	2	0.75	38.53	5.71	9,971	309.88	8,568,410
Deep Creek	Granite	5,967	33′ 5″	2	0.75	38.53	5.71	9,971	323.18	3,856,821
Deadman Creek	Granite	8,770	33′ 5″	2	0.75	38.53	5.71	9,971	307.69	5,396,817
Pleasant Prairie	Granite	16,640	33′ 5″	2	0.75	38.53	5.71	9,971	303.00	10,083,948
Manito	Basalt and earth.	15,450	33′ 5″	2	0.75	38.53	5.71	9,971	343.95	10,628,080
Bonnie Lake	Basalt	83,260	31′ 4″	2	1.14	34.14	5.15	10,089	276.73	46,081,166
Patterson	Basalt	3,700	33′ 5″	2	0.75	38.53	5.71	9,971	337.61	2,498,344
										$105,507,841
NORTH DIVISION—										
McElroy	Basalt	8,200	28′ 9″	1	0.75	28.49	4.35	6,839	249.11	$2,042,712
Paha	Basalt	2,000	28′ 9″	1	0.75	28.49	4.35	6,839	249.18	498,353
Klemmer	Basalt	20,300	28′ 9″	1	0.75	28.49	4.35	6,839	249.03	5,055,406
Low Gap	Basalt	9,500	15′ 0″	1	0.757	8.20	1.60	1,278	97.67	927,874
										$8,524,345
CENTRAL DIVISION—										
Providence Main "CC"	Basalt and earth.	3,000	26′ 3″	1	1.15	23.94	3.77	6,412	217.50	$652,496
Providence Main "CD" No. 1	Basalt and earth.	3,300	26′ 3″	1	1.15	23.94	3.77	6,412	217.62	718,138
Providence Main "CD" No. 2	Basalt and earth.	1,400	26′ 3″	1	1.15	23.94	3.77	6,412	217.74	297,836
										$1,668,470
SOUTH DIVISION—										
South Main	Basalt and earth.	3,900	33′ 0″	1	1.25	37.45	5.60	12,194	315.08	$1,228,800
Snake River Main "SF"	Basalt and earth.	3,000	21′ 6″	1	1.30	16.02	2.62	3,904	160.17	480,523
Snake River Main "SG"	Basalt and earth.	6,000	20′ 9″	1	1.36	14.98	2.50	3,557	150.78	904,705
Snake River Main "SH"	Basalt and earth.	1,320	17′ 9″	1	1.25	11.09	2.05	2,808	123.67	163,248
Eureka Main "SJ" No. 1	Basalt and earth.	1,500	15′ 0″	1	2.30	8.02	1.62	1,690	98.26	147,389
Eureka Main "SJ" No. 2	Basalt and earth.	7,920	15′ 0″	1	2.30	8.02	1.62	1,690	97.86	775,034
										$3,699,699
Grand Totals		419,846 feet, equals 79.52 miles, single bore								$119,400,355

Between Scotia and Camden, it will be necessary to move the Great Northern Railroad from the canyon of the Little Spokane River, as this will be flooded by the enlarged Chain Lakes. A tunnel has been planned for the railroad which will very largely reduce the curvature in the present line and protect the railroad from the drifted snow which occasionally makes trouble in the canyon. Construction of this tunnel must be started as soon as the project is authorized, owing to the necessity of diverting the rail traffic before any considerable work can be done on the Camden dam, and the channel above Chain Lakes The quantities and costs involved in this relocation are as follows:

Table No. 31 — COST OF GREAT NORTHERN CHANGE.

ITEM	Unit	Quantity	Unit Cost	Cost
Penrith, west	Mile	3.05	$124,154	$378,670
Scotia, west	Mile	1.52	64,058	97,368
Camden Tunnel—				
Right of way and clearing	Acre	55	....	2,250
Tunnel excavation	Cu. Yd.	291,764	6.50	1,896,466
Overhaul	Yd.-Mi.	437,646	.30	131,294
Transfer of track	Mile	4.53	....	17,305
Engineering				20,000
				$2,543,353
Contingencies				200,000
Total cost				$2,743,353

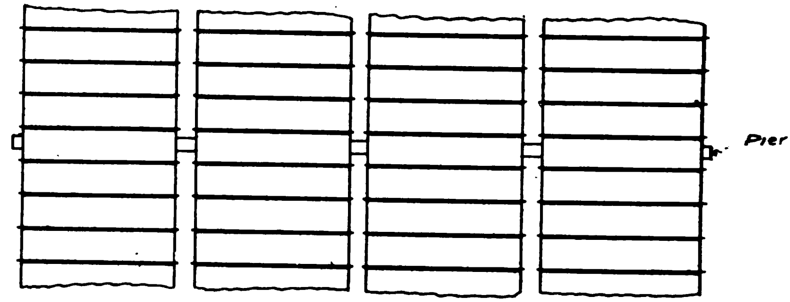
(5) *Inverted Siphons.* Designs and detailed estimates were made for inverted siphons built of steel, of reinforced concrete, and of wood stave. On the supply canal and the main distribution canals, the volume of water to be carried is greater than can be handled by one pipe. Where the pressure heads are low enough to permit of pipes 23 feet in diameter being used, four such pipes will carry the flow. As the heads increase and the limits of tensile stress necessitate the use of smaller pipes, the number of units required increases. Increasing the number of pipes permits of postponing a portion of the installation until the project approaches full development, with the consequent saving of capital investment during the earlier years. Steel siphons are used for the larger volumes, and for all volumes under heads exceeding 100 feet. Reinforced concrete inverted siphons are used at the lower heads, as in the railroad under-passes.

Concrete piers will be placed under all siphons, keeping the pipes clear of the ground and affording ready access for installation and maintenance. These piers will be reinforced with steel and will embrace the lower one-third of each pipe.

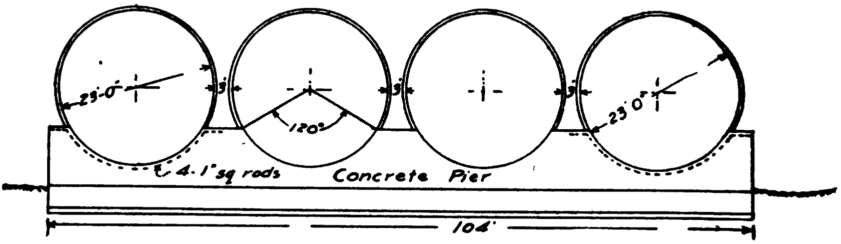
Since the piers embrace only 120 degrees of the pipe circumference they will not be affected by the tendency of the pipe to bcome wider at the horizontal axis when emptied. Furthermore, the angle iron stiffening rings shown in the designs are expected to entirely eliminate the distortion in shape between the filled and emptied pipe. Massive anchor piers are included in the estimates of those siphons which are of considerable length or traverse steep hillsides.

It is expected that it will be possible to build the siphons of steel having unusually favorable qualities, high tensile strength, resistance to rust, etc. By contracting for the large quantities needed, probably two or three years in advance, these qualities can be provided at a price not greater than is paid for ordinary steel required for quick delivery, or if it is desirable to use the usual grade of steel, this can be purchased far enough ahead of delivery to assure a comparatively low price. In either event, the project will receive the advantage of ordering the steel sufficiently in advance of requirements to enable the rolling mills to make an exceptional price.

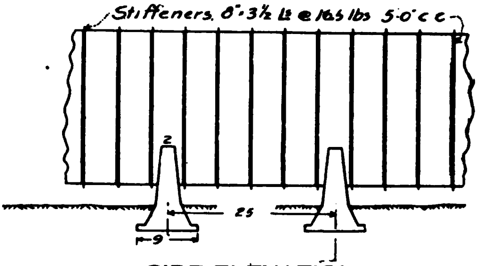
In the cost estimate, the base price has been taken at $2.65 per hundred pounds, this being the Pittsburgh quotation at this time. To this has been added $0.35 for shaping, punching, and shop painting, $1.25 freight, $2.00 for erection, $0.60 for equipment, and $0.15 for incidentals. The estimates can be modified at any time by altering the price per pound to agree with the change in Pittsburgh base from $2.65. The controlling factors, quantities, and estimated costs of the several siphons are tabulated following.



PLAN



SECTION



SIDE ELEVATION

Hydraulic Functions

Dia. = 23'-0"   n = .015

P = 72.3'   s = .0015

R = 5.75   v = 12.0

A = 415.5   Q = 4994

One Pipe

SUPPLY CANAL
INVERTED SIPHON
COLUMBIA BASIN PROJECT
STATE OF WASHINGTON
1920

FIG. 31.

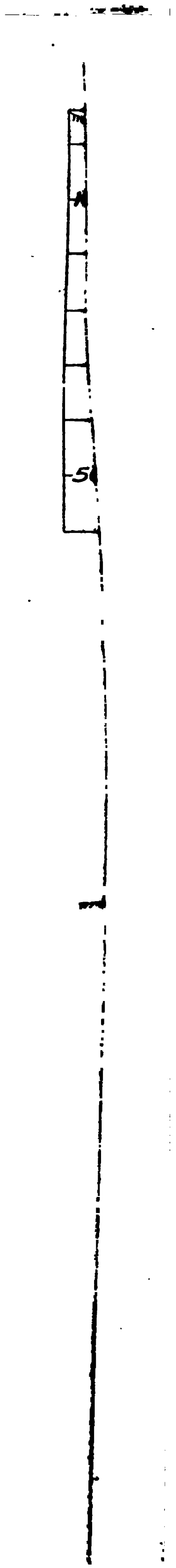


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Table No. 32—COST OF INVERTED SIPHONS.

Inverted Siphon No.	LOCATION	RIGHT OF WAY		SIPHON STEEL		EXCAVATION FOR PIERS		CONCRETE IN PIERS		REINFORCING STEEL IN PIERS		CONCRETE IN TRANSITIONS Light Reinf'rcem't	
		Acres	Cost at $30.00 per Acre	Pounds	Cost at 7c per Pound	Cubic Yards	Cost at $1.00 per Cu. Yd.	Cubic Yards	Cost at $15.00 per Cu. Yd.	Pounds	Cost at 6c per Pound	Cubic Yards	Cost at $19.00 per Cu. Yd.

Table No. 32 — COST OF INVERTED SIPHONS — Continued

Inverted Siphon No.	LOCATION	RIGHT OF WAY		SIPHON STEEL		EXCAVATION FOR PIERS		CONCRETE IN PIERS		REINFORCING STEEL IN PIERS		CONCRETE IN TRANSITIONS Light Reinf'rcem't	
		Acres	Cost at $30.00 per Acre	Pounds	Cost at 7c per Pound	Cubic Yards	Cost at $1.00 per Cu. Yd.	Cubic Yards	Cost at $15.00 per Cu. Yd.	Pounds	Cost at 6c per Pound	Cubic Yards	Cost at $19.00 per Cu. Yd.
30	Main "SH"	4	120	2,480,000	173,600	3,088	3,088	2,960	44,400	35,200	2,112	550	10,450
31	Snake River	18	540	48,463,600	3,392,452	21,430	21,430	17,530	262,950	183,800	10,998	550	10,450
32	Lateral "S41"	10	300	3,240,000	226,800	....	....	876	13,140	....	....	....	....
33	Lateral "S86"	4	120	960,000	67,200	....	....	280	4,200	....	....	....	....
	Totals..............	228	$7,020	371,991,604	$26,039,409	186,827	$191,623	248,739	$3,731,085	4,747,455	$284,846	30,089	$571,691

Table No. 32 — COST OF INVERTED SIPHONS — Continued

In.	CONCRETE IN TRANSITIONS Heavy Reinf'rcem't	Railroad Spur and	EXCAVATION FOR TRANSITIONS	MISCELLANEOUS EXCAVATION			BLOW-OFF VALVES			

Table No. 32 — COST OF INVERTED SIPHONS — Concluded.

Inverted Siphon No.	CONCRETE IN TRANSITIONS Heavy Reinf'rcem't		Railroad Spur and Traffic Maintenance	EXCAVATION FOR TRANSITIONS			MISCELLANEOUS EXCAVATION			Special Items	BLOW-OFF VALVES		Engineering	Contingencies	Total Cost
	Cubic Yards	Cost at $27.00 per Cu. Yd.		Cubic Yard	Per Unit	Cost	Cubic Yard	Per Unit	Cost		Number	Cost at $500.00 Each			
20	12	324	5,000								2	1,000	4,000	2,000	160,041
21	33	891	5,000				2,038	1.20	2,446	F 3,000	7	3,500	7,000	3,000	287,006
22	1,460	39,420	5,000								2	1,000	9,000	7,000	497,799
23	400	10,800					800	1.20	960	F 1,000 T 32,500	5	2,500	25,000	15,000	1,068,494
24							19,228	1.20	23,074	F 6,000 T 45,000	13	6,500	28,000	20,000	1,222,256
25										T 3,250	2	1,000	1,000	1,000	69,655
26										T 1,875	1	500	6,000	1,000	208,415
27										T 5,250	1	500	4,000	2,000	175,990
28										T 1,800	3	1,500	1,000	200	48,360
29	675	18,225	2,500				20,072	.50	10,036	F 16,000	4	2,000	103,500	30,000	3,991,122
30	520	14,040	2,500							T 1,375	2	1,000	5,200	5,000	262,885
31	220	5,940	2,000				17,300 7,682	.25 2.00	4,325 15,364	C 5,880 S 662,031 B 328,650 A 15,060 R 210,000	2	1,000	101,700	86,500	5,137,270
32										T 3,250	1	500	7,000	1,300	252,290
33													2,000	400	73,920
Totals.	21,049	$568,323	$102,000	77,972		$28,566	160,395		$140,957	$1,795,569		$47,500	$779,500	$514,750	$34,802,839

H—Highway crossing.
F—Preparation footings.
S—Structural steel.
A—Concrete in abutments.
T—Transportation.
E—Rock embankment in lake.
C—Concrete S., P. & S. crossing.
B—Concrete bridge piers.
R—Cofferdam river piers.

Table No. 33—RECAPITULATION OF INVERTED SIPHONS.

(6) *Spokane River Aqueduct.* Several methods of crossing the Spokane River were studied before the present design was adopted. An inverted siphon of steel or reinforced concrete under the river was considered but was rejected on account of the difficulty of access for examination and maintenance. A tunnel acting as an inverted siphon was rejected because the river bed to an unknown depth is composed of beds of sand and gravel interspersed with boulders and carrying a large flow of water. Any type of inverted siphon would create a loss of head which would decrease the fall available and therefore increase the cross-section of the tunnels south of the Spokane Valley.

A steel through-truss bridge cannot be used on account of the excessive load, which is far greater than that borne by existing steel bridges. The truss bridge would also have inadequate clearance above the river.

The adopted design calls for reinforced concrete arches supporting a reinforced concrete flume which is to be carried on steel hangers, extending into the arch ribs. This provides ample clearance for the highest floods in the river.

Five parallel arches support the flume in four sections, each designed to carry its load independently of the others.

A stilling basin is provided on the north shore where sediment will be caught and discharged through the wasteway gates. A spillway in solid rock will be constructed capable of diverting the entire canal flow into the river. Four steel gates will close the entrance to the flumes and four similar gates will close the wasteway. Figs. 33 and 34 show the general outline of the structure and the estimated quantities and costs follow.

5'
20'

Table No. 34.

COST OF SPOKANE RIVER CROSSING.

ITEM	Unit	Quantity	Unit Cost	Cost
Right of way	Acre	10	$50.00	$500
Cofferdams, pumping, etc., for piers				30,000
Excavation, south abutment	Cu. Yd.	11,734	1.00	11,734
Excavation on approach channel	Cu. Yd.	12,360	1.00	12,360
Excavation for wasteway chute	Cu. Yd.	34,588	1.25	43,235
Excavation for outlet transition	Cu. Yd.	7,950	.25	1,988
Concrete in two river piers	Cu. Yd.	6,728	20.00	134,560
Concrete, plain 1:3:6	Cu. Yd.	5,974	15.00	89,610
Concrete in structure, with light reinforcement	Cu. Yd.	9,096	19.00	172,824
Concrete in structure, with heavy reinforcement	Cu. Yd.	5,951	27.00	160,677
Concrete, light reinforcement for canal lining	Cu. Yd.	3,180	18.00	57,240
Structural steel in place	Lb.	4,269,000	.08	341,520
Gunite coating on I beams	Sq. Ft.	158,850	.06	9,531
Steel gates and operating mechanism				120,000
Rip rap, hand placed	Cu. Yd.	1,250	3.00	3,750
Engineering				28,000
				$1,217,539
Contingencies				50,000
Total cost of Spokane River crossing				$1,267,539

(7) *Railroad Underpasses.* These structures are the ordinary type of short concrete inverted siphons and involve no unusual features of design. The quantities and estimates of the several underpass structures are as follows:

Table No. 35 — RAILROAD UNDERPASSES.

RAILROAD	Canal Crossed	Location	STRUCTURAL STEEL		CONCRETE			EXCAVATION			Traffic Maintenance	Engineering	Totals
			Quantity Pounds	Amount at 9c per Pound	Quantity Cubic Yards	Unit Cost	Amount	Cubic Yards	Unit Cost	Amount			
S. & Int.	Main Supply	Spokane Valley	375,000	$33,750	80	$15.00	$1,200				$1,000	$1,000	$36,950
S. & E.	Main Supply	Spokane Valley	480,000	43,200	100	15.00	1,500				1,000	1,300	47,000
N. P.	Main Supply	Spokane Valley	1,569,000	141,210	1,650	15.00	24,750				1,000	5,000	171,960
C., M. & St. P.	Main Supply	Spokane Valley	261,500	23,535	670	15.00	10,050				1,000	1,000	35,585
S. T. Co.—Vera Line	Main Supply	Spokane Valley	264,625	23,816	80	15.00	1,200					800	25,816
S., P. & S.	Main Supply	Near McCall	375,000	33,750	62	15.00	930						34,680
O.-W. R. & N.	Main Supply	Near Marengo			2,680	19.00	50,920				3,000	4,000	142,700
					3,140	27.00	84,780						
C., M. & St. P.	"M1"	Near Marengo			46	27.00	1,242	180	$0.50	$90	1,000		2,332
C., M. & St. P. Branch	"N3"	S. 14-19-30	21,140	1,903	90	15.00	1,350					100	3,353
Connell Northern	"N31"	S. 26-19-29	16,530	1,488	90	15.00	1,350					50	2,888
C., M. & St. P. Branch	"N31"	S. 9-18-29	16,530	1,488	90	15.00	1,350					50	2,888
Connell Northern	"N4"	S. 30-20-29	16,530	1,488	90	15.00	1,350					50	2,888
G. N.	"NJ"	West of Quincy	59,800	4,784	3,906	27.00	105,462	350	1.00	350	2,500	1,030	114,126
Connell Northern	"O56"	S. 5-16-30	21,140	1,903	90	15.00	1,350					100	3,353
Connell Northern	"OF"	S. 25-15-30	28,400	2,356	47	27.00	1,269	2,000	.60	1,200	2,500	400	13,710
					315	19.00	5,985						
N. P. Branch	"SK"	S. 20-10-34	32,490	2,924	90	15.00	1,350					120	4,394
N. P. Branch	"SK"	S. 31-10-34	32,490	2,924	90	15.00	1,350					120	4,394
N. P. Branch	"S8"	S. 20- 9-33	16,530	1,488	90	15.00	1,350					50	2,888
O.-W. R. & N.	"S84"	S. 35- 9-31	13,480	1,213	90	15.00	1,350					50	2,613
Totals			3,600,185	$323,220	13,586		$301,438	2,530		$1,640	$13,000	$15,220	$654,518

(8) *Miscellaneous Structures.* A large number of miscellaneous structures are necessary. These do not justify reproduction of the designs and reference is made to them because in the aggregate they total a considerable sum.

Telephone lines totalling 1,103 miles have been planned to extend throughout the length of all canals. On account of the importance of maintaining a rigid control of the system at all times, it is advisable that a double circuit be maintained on the supply canal and on the main distribution canals. These have been figured as all metal circuits, one on each side of the canal, with telephones installed at each canal tender's house and plug-in stations along the line at short intervals.

At road crossings, standard bridges of steel or reinforced concrete will be provided. Fencing has been included for 1,054 miles of the canals. Various other items will be noted which are self-explanatory.

APPENDIX D.

DRAINAGE AND WASTEWAYS.

It is impracticable to design a complete drainage system for a large area in advance of actual irrigation and observation of its effect on the ground water level. Underground flows, or conditions favorable to flow if water were present, are necessarily difficult to study. No attempt has been made, therefore, to plan a detailed system of artificial drains.

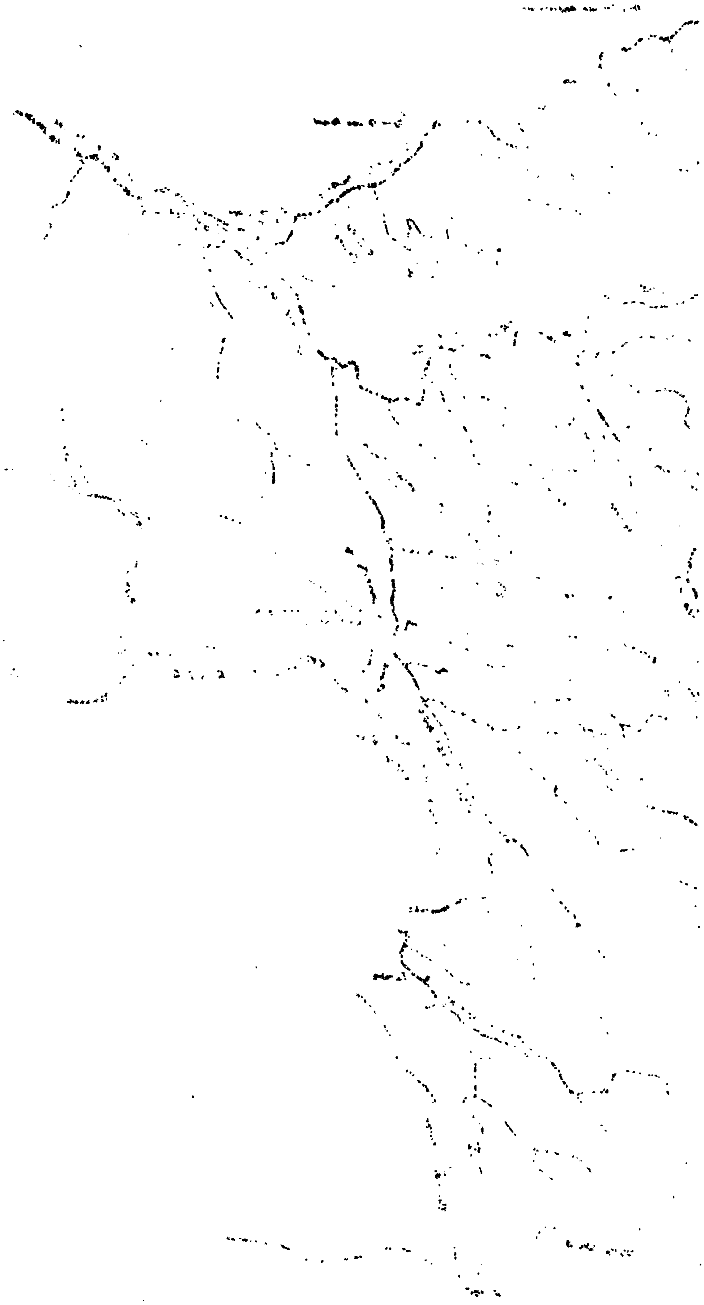
It is believed that the gravel or sand strata which underlie portions of the Columbia Basin area will act as natural and adequate drainageways to carry percolating waters into the deep-cut and numerous draws and coulees. The map opposite shows clearly the numerous lines of surface drains which would carry running streams were there sufficient rainfall. These drainage courses afford a network which as completely covers the area as does the distribution system. Note that a natural drain exists between practically every pair of laterals. Only near Moses Lake is there need for a few ditches to drain areas lacking in coulees.

The existence of this complete natural drainage system will prevent serious water-logging in the project. Only short drains of small capacity will be required in local, flat areas which may lack underground conditions affording drainway connection with the coulees.

The many coulees not only afford a satisfactory drainage system, but solve the problem of wasteways to carry off the surplus water from the canals. The normal operation of a canal system results in frequently having to waste excess water. Each intersection of a canal with a draw affords opportunity for construction of a spillway, whose size depends upon the volume of water in the canal and the capacity of the drainage course below.

Reconnaissance surveys were made along the several distributing mains and the supply main, showing the following named places to be available:

(1) *Wasteways on Supply Canal.* Between Albany Falls and the Spokane River the capacity of the several creeks crossed is small, not exceeding a few hundred cubic feet per second. They are therefore of little value as wasteways. The four lakes on this section of canal will have sufficient capacity



to absorb all the water in the canal, as shown under chapter "Secondary Storage."

At the Spokane River, a wasteway will permit of discharging the full flow of the canal. The Spokane River can carry this quantity of water without damage, excepting at extreme flood height. As the river flood has passed each year before the canal reaches its maximum load no conflict can occur.

At Latah Creek the lake will act as a reservoir for taking waste water. Also probably 10,000 second-feet could be discharged at the spillway over the dam and enter the Spokane River a short distance below. Wasteway will not be needed at Rock Lake, as the lake can hold the contents of the supply canal with less than four feet rise of surface. A large flow could be sent down Rock Creek if necessary, although the maximum capacity of the canal could not be so discharged, owing to the presence of a railway in the valley, and low bridges over the stream.

At Wassun Creek a railway bridge restricts the outlet of the valley, which would require alteration. The same is true of Dragoon Creek. At both places some lands would have to be acquired along the stream channels to provide for the larger capacity required.

Cow Creek is not available for wasteway purposes, owing to the presence of a railway the entire length of the stream and the high stage of development of the adjacent farm lands.

(2) *Wasteways Along North Main.* At McElroy Lake a low dam and spillway will provide capacity for storing 2,500 acre-feet of the waste from the North Main below Wassun Creek. The balance will flow into Lind Coulee where some channel improvements will be required. After the coulee enters Grant County no further improvement will be needed, as the channel is large and well defined from that point to its junction with Crab Creek.

At Third Coulee the canal crosses on a fill. By constructing this fill as a dam, a waste water storage will be provided sufficient to hold the water in the main canal between there and the spillway at McElroy Lake, about 1,000 acre-feet. This can be released down Third Coulee from the lake at the rate of two to three hundred second-feet without doing damage to adjacent property.

Second Coulee will carry 400 to 500 second-feet to its junction with Third Coulee. The only expense will be for the discharge gates.

A storage reservoir can be built in First Coulee of sufficient capacity to take the contents of the main canal as far back as the Wassun Creek wasteway. The area of this reservoir will be 1,180 acres, and the additional depths of water caused by draining the canal will be as follows:

Draining from Third Coulee to First Coulee, 2,450 acre-feet, 2.0 ft. rise.

Draining from McElroy Coulee to First Coulee, 3,500 acre-feet, 3.0 ft. rise.

Draining from Wassun Creek to First Coulee, 6,300 acre-feet, 5.4 ft. rise.

The cost of this improvement is given in Table No. 38 under "Secondary Storage."

The floor of Black Rock Coulee is largely rock, with no agricultural lands. First Coulee reservoir will normally take the waste from above that point, leaving but 800 acre-feet in the canal between there and Black Rock. There exists in the latter coulee natural storage without dams, exceeding 4,000 acre-feet, making it possible to drain into this coulee the canal contents practically from McElroy Coulee to Black Rock.

In lower portion of Black Rock Coulee, Artesian Lake offers opportunity for creating a reservoir of 1,440 acres area. Storing water in such a lake will result in surface rise as follows:

From First Coulee to Black Rock, 800 acre-feet, 0.55 ft. rise.

From Third Coulee to Black Rock, 3,250 acre-feet, 2.25 ft. rise.

From McElroy Coulee to Black Rock, 4,300 acre-feet, 3.00 ft. rise.

From Wassun Creek to Black Rock, 7,100 acre-feet, 5.00 ft. rise.

A storage reservoir in Black Rock Coulee would retain the water from the canal from Wassun Creek down. Since this water could be used for irrigation on areas below the lake, this cost would be charged to secondary storage. (Table No. 38.)

It is necessary to construct a drainage ditch 9.11 miles long to carry excess water from either First Coulee or Black Rock Coulee to Crab Creek.

Broken Rock Coulee contains many potholes and can absorb the 500 acre-feet in the canal between there and Black Rock Coulee without creating outflow in either direction.

Near Adrian, Crab Creek has capacity to carry the flow from the North Main, 4,230 second-feet, with very little improvement of the channel. Some protection might be required at the railway bridge and a wasteway would be excavated from the canal to the creek. By acquiring the low area of 400 acres west of Adrian and using it as a retaining basin to retard the crest of the discharge, the 800 acre-feet wasted from the canal could be stored for use in irrigating the bottom lands down the creek.

On lower Crab Creek, from Moses Lake to Beverly, there is but little land of value. The channel of the stream will carry several hundred second-feet flow. The valley bottom could be flooded without damage and made to carry the full capacity of any of the canals immediately above. At some points the channel might become enlarged by flooding, while at others the water would spread over a fourth mile of width. The railway is sufficiently elevated above the bottom to escape damage.

Should it be desirable to purchase all the lands subject to flooding by extreme overflow conditions, about 15,000 acres would be acquired. If future demand for farming lands justifies reclaiming this area, it can be easily done by a drainage ditch and enlarging and straightening the present creek channel.

Along the Babcock Main, the Willow Spring and the Frenchman Springs canyons afford ample capacity for discharging the full flow of the canal into the Columbia River. In the Willow Spring canyon a few thousand yards of channel excavation may be needed and two highway bridges will be necessary. Numerous small canyons may be used for excess water from the various laterals. Water south of Frenchman Hills can be discharged through Red Rock Canyon to Crab Creek and through Sand Hollow to the Columbia River.

(3) *Wasteways Along Central and South Mains.* Water discharged from the canals between head of Snake River Main and Sand Coulee spillway, or from the South and Providence Mains between Pazara tunnel and Fairview school, will enter Rattlesnake Canyon. Seven thousand second-feet could be disposed of by storage in Rattlesnake Canyon or by permitting it to enter Sulphur Lake in Washtucna Coulee or by a channel to Esquatzel Coulee.

Sulphur Lake has a surface elevation of 680. The available storage capacity below 740, which is the railway elevation at this point, is 2,300 acre-feet. This could be increased to 5,000 acre-feet by changing 3.5 miles of railway. It is probable that not over 3,000 acre-feet would be turned into the lake at any one period. This water should evaporate and seep away without endangering the railway.

The Sand Coulee wasteway will have a capacity equal to the flow in Snake River Main, 4,370 second-feet. The natural rocky channel of Sand Coulee will carry the water to a quarter mile north of Kahlotus, without damage. From the mouth of the canyon, past the town of Kahlotus and into Washtucna Lake, about 3,500 feet, rock rip-rap will be necessary to protect the bank from erosion and consequent damage to property. The railway trestle affords sufficient clearance, but the highway would require a bridge east of the town.

Washtucna Lake has an area of 380 acres at elevation 880. The railway at 885.5 prohibits raising the water above 883 at maximum flood. It is proposed to construct a weir which will pass the 4,370 second-feet between elevations 880 and 883. This weir will discharge through a tunnel into Devils Canyon. Devils Canyon leads to the Snake River, and will require two railway bridges.

Old Maid Coulee and Smith Canyon may be used as wasteways with little or no expense. Both lead to the Snake River. Three reservoir sites exist in these canyons where secondary storage may be utilized. A number of small draws and coulees run to the southwest, each offering excellent spillway facilities.

(4) *Wasteways Along Mains of Central Division.* Kludos, Hatton, and Cunningham coulees and their branches will carry the waste water from the distributing canals into Providence Coulee. The probable maximum discharge into the coulee will never be more than 6,500 second-feet, which rate of flow will last but a short time. If the Rattlesnake spillway is provided, the maximum discharge into Hatton Coulee would not exceed 700 second-feet. Small dams and reservoirs can be provided in the several coulees to retard large flows, and release the water at a rate which would pass through the lower valleys without damage. Adequate natural channels already exist, and no farm lands are subject to flooding.

Water turned out of the Providence and Shano mains, and the drainage from the area south and east of these canals, will enter Providence and Esquatzel coulees, without damage.

From Providence to Connell the Providence Coulee is narrow, with rocky sides and no agricultural lands. From 1,000 to 1,500 second-feet can be discharged in this coulee without damage. The railway is on a fill 10 to 15 feet above the bottom of channel, with bridge openings of 50 feet in the clear. This fill would require rock paving for protection. Cunningham and Hatton are in the coulee but a small amount of channel improvement will protect these towns.

Drainage and waste water from the West Pasco Main and its laterals to a point due west of Mesa would enter Esquatzel Coulee. Beyond that place, drainage will be to the west into south branch of Koontz Coulee and the Columbia River near Ringold. Koontz Coulee has a broad bottom, of good soil and slight slope, and might in time require construction of a drainage channel about six miles long.

West of Kansas Prairie, the natural drainage is excellent, leading north into Lind Coulee, west to Crab Creek, and south into Skootenay Lake. Any drainage or waste from Saddle Mountain Main and the country east of Saddle Mountains will also enter Skootenay Lake. This and bordering lake basins have a natural storage capacity of about 50,000 acre-feet. The overflow above this capacity will run to the south and west through Koontz Coulee to the Columbia River. These basins should rapidly empty by evaporation and seepage through the walls and bottoms. The capacity will thus again be available within a short time after each filling.

West of Skootenay Lake several natural drainage ways will carry waste water into the Columbia River.

Table No. 36.

COST OF SPILLWAYS AND WASTEWAYS.

LOCATION	Cost	Contingencies	Total Amount
On Main Supply—			
Wassun Creek	$641,091	....	$641,091
On Distribution System—			
Sand Hills Coulee	541,757	$26,557	568,314
Rattlesnake Canyon	186,622	9,148	195,770
Providence-Esquatzel Coulee	243,949	11,958	255,907
McElroy-Lind Coulee	341,896	16,760	358,656
Third Coulee Catch Basin	61,803	3,030	64,833
Skootenay Springs	16,994	833	17,827
Drainage lower end First Coulee	50,772	2,489	53,261
Black Rock Coulee	17,544	860	18,404
Broken Rock Coulee	37,740	1,850	39,590
Crab Creek at Adrian	85,680	4,200	89,880
Lower Crab Creek	153,000	7,500	160,500
Willow Spring Canyon	22,624	1,109	23,733
Frenchman Springs	20,935	1,026	21,961
Red Rock Canyon	16,795	823	17,618
Minor Wasteways	500,000	....	500,000
Totals	$2,989,202	$88,143	$3,027,345

Appendix E.

SECONDARY STORAGE.

(1) *Along the Main Supply Canal.* Each of the six dams on the main supply canal between Albany Falls and Hillcrest offers opportunity for creating a small amount of secondary storage. The value of such storage lies in the capacity provided for holding in each lake water which would otherwise be wasted from the main canal after a shut-down. Each of the dams is designed with crest elevation 13 feet above the normal water surface, and of the capacity thus provided five feet could safely be used for emergency storage during short periods of time. The following table shows the acre-feet storage created by such super-elevation of the water surface. It also shows the volume of water in the canal, when running at full capacity, between each lake and the outlet of the next higher lake, and the increase in depth of the lower lake which is necessary to hold that volume. On assumptions of five feet elevation of spillway above normal water surface, the last column states the length of time which all the gates above any dam may remain open before the water overtops the spillway at the dam.

Table No. 37.

SECONDARY STORAGE ON SUPPLY CANAL.

NAME OF LAKE	Acre-Feet of Storage for Rise of Water Surface of 5 Feet	Volume of Water in Canal Below Preceding Lake and Rise in This Lake to Hold That Volume		Length of Time All Gates Above Can Remain Open Without Over-Topping Spillway on a Free-Board of 5 Feet
		Acre Feet	Feet	
Chain	2,675	2,200	4.27	14 min.
Deep Creek	4,225	2,480	3.00	0
Deadman Creek	10,838	435	0.28	4 hr. 17 min.
Latah Creek	8,025	3,270	2.00	0
Rock Creek	16,700	3,160	1.00	3 hr. 7 min.

If the gates at Albany Falls and at Rock Lake are closed, the entire contents of the canal between these points would raise the water surface in the latter lake 3.3 feet.

Starting with Rock Lake and closing each set of gates up-stream in turn as soon as the surface of the next lake below has been raised five feet, more than 25 hours will elapse before the diversion gates at Albany Falls must be closed to prevent overflow of the spillways. This allows ample time for closing the emergency gates at Albany Falls in the event of an accident preventing operation of the control gates at this point.

It will be observed that in no case is five feet of storage required to hold the water from the next section of canal above. The outlet gates were therefore designed to control the water surface for not more than five feet rise above the normal elevation.

The stored water in this lake system is sufficient to permit resumption of full water service after a shut-down twenty-four hours sooner than would be possible without this secondary storage.

The several lakes, acting as temporary reservoirs, are the same as a series of valves in a pipe line providing immediate stopping or starting of flow and guarding against the loss of water and any possible consequent damage, because of accidental interference with the operation of the canal. This is a remarkable and very unusual feature on large canals and will be of great assistance in the operation of the system.

(2) *Secondary Storage on the Project.* The construction of dams to take care of overflow from the wasteways will provide auxiliary storage at several points. A certain amount of secondary storage can be utilized at each of these reservoirs and still at each place retain sufficient storage capacity to absorb the discharge from the canals above. The extent to which such storage should be developed can only be determined after more detailed surveys of each location and of the lands that can be served.

It is evident that the greater the storage capacity of each reservoir, the greater will be the service in reducing the maximum demand on the main canals, provided there is sufficient irrigable land below the dam to utilize the water thus stored. It is also evident that the entire cost of developing a particular site should not be charged against the secondary storage alone since some development is imperative as a part of the wasteway and drainage system. Nor can the design of the main canals be refigured for smaller capacities until the amount of secondary storage has been carefully determined.

No reduction has therefore been made in the proposed size or estimated cost of the canals on account of the possibilities of secondary storage. It should be borne in mind, however, that the creation of such storage will effect a substantial reduction in the required maximum capacity of supply works and a corresponding reduction in cost. It is also possible that the development of secondary storage after the construction of the main canals will permit of increasing the total acreage to be irrigated. This would allow the various pumping projects to be installed without overloading the canals.

Secondary storage along the North Main canal will likely be in the First Coulee. Such storage would provide water for 75,000 acres lying below the First Coulee during July and August, and reduce the demand on the North Main and the Supply Canal. This would permit reducing the maximum capacity of the canals named by 800 second-feet. The resulting saving in cost would probably more than pay for the First Coulee development.

A secondary development in Black Rock Coulee would store water for approximately 20,000 acres, but would have only a small effect in reducing the maximum capacity of the North Main and Supply Canal.

Secondary storage in Rattlesnake Canyon, Smith Canyon and both reservoir sites in Old Maid Coulee, would be available to carry the peak load for about 70,000 acres lying in the Pasco area. One or more of these reservoirs might prove economical to develop. The water from them would be picked up by canals running east and west from near Eltopia, and would irrigate all land lying south of these canals.

The cost of providing secondary storage has not been included in the general estimate for the Columbia Basin Project for the reason that such expense would not be incurred unless it resulted in an equal or greater decrease in the cost of the main system. The estimate on the main system is therefore ample to include the cost of any secondary development.

The larger reservoirs which might be developed, and the approximate storage and costs involved, are listed in the following table:

Table No. 38 — CAPACITIES AND COST OF SECONDARY STORAGE DAMS.

LOCATION	Cost	Acre-Feet Stored	Cost per Acre-Foot
First Coulee	$2,548,756	68,840	$37.02
Rattlesnake	3,059,200	181,250	16.88
Smith Canyon	2,084,500	128,710	16.20
Old Maid (Upper)	1,983,750	54,260	36.56
Old Maid (Lower)	1,944,100	56,510	34.40
Black Rock	1,547,100	51,220	30.20

In the Eureka Flats area a reservoir site exists in Wynett Canyon. It appears from a reconnaissance survey and other information that approximately 100,000 acre-feet could be stored at this place and could be released for use along the Touchet River and the lower reaches of the Walla Walla River. Probably canals could be taken directly from the reservoir to supply certain lands lying below elevation of approximately 800 feet. In the event that this site should be developed for the benefit of lands in that area, the Columbia Basin Project might fill the reservoir, either as a part of its own development or as a supplemental water supply under contract with the districts or persons developing the storage. If developed as a part of this project, it would effect a reduction in the peak demand on the Snake River Main and a consequent saving in the cost of the Snake River siphon probably sufficient to pay for the development at Wynett Canyon.

It should be understood that the estimates given for all the secondary storage reservoirs are for the maximum feasible development. This may not be the economic capacity, as the lands below any site may not be sufficient in extent to justify the largest possible storage above. However, considering each of the several reservoirs from the two standpoints of value for auxiliary storage and usefulness in controlling water which would otherwise run to waste, it follows that a thorough study of all factors will be justified before rejecting any reservoir.

Appendix F.

POWER POSSIBILITIES.

(1) *Power From Drops on the Project.* Of the numerous drops on the distributing canals there are twenty-five where power development may be advisable. The maximum flow and total fall of the water varies from 4,950 second-feet under 49 feet head to 300 second-feet under 350 feet head. Of the power so developed, less than 15,000 horse power would be required for pumping onto 65,000 acres with a lift of 100 feet or less, and 26,000 acres at not over 150 feet head. About ten per cent of these areas would be served by direct connected pumping units, the balance requiring transmitted power.

The energy not used for pumping could be made available for any industry capable of utilizing the fluctuating amount of surplus power. The following table gives the maximum figures, these corresponding with the monthly flow of water, given in Table No. 8:

Table No. 39 — THEORETICAL POWER FROM CANAL DROPS.

MONTH	Per Cent. of Seasonal Flow	Per Cent. of Maximum Flow	Theoretical Power at Drops	Power Delivered to Transmission Lines at 75%	Pumping Load	Surplus Available for Commercial Use
			H. P.	H. P.	H. P.	H. P.
January to March	0	0	0	0	0	0
April	7.65	37.46	94,876	71,157	5,483	65,674
May	14.92	73.07	185,066	138,800	10,696	128,104
June	16.00	78.35	198,439	148,829	11,469	137,360
July	18.68	91.48	231,694	173,770	13,390	160,380
August	20.42	100.00	253,273	189,955	14,638	175,317
September	13.80	67.58	171,162	128,372	9,892	118,480
October	8.53	41.77	105,792	79,344	6,114	73,230
November to December	0	0	0	0	0	0

It is not apparent what use could be made of the excess power except in connection with some other source of power which could conserve its potential energy during the irrigating season by using the surplus from the canal drops. During the remaining months the load must be taken care of by auxiliary power.

By "tieing-in" to a transmission system which derives part of its energy from stored water, the draft from storage could be reduced in proportion to the power being received from the drops. This would be a valuable asset in the case of a power system whose market is greater than its available energy.

The cost of developing power at the drops has not been included in the estimated cost of the irrigation system. If future economic and industrial conditions create a demand for such power as can be generated at the canal drops, the power consumer may either lease the right and pass the water through his own hydraulic plant or contract for mechanical or electric power at a price justifying the installation of a generating plant by the irrigation district. In either case a revenue would be received by the project which would reduce the annual water charges.

(2) *Power Possibilities on Flathead and Clarks Fork Rivers.* The fall in the Flathead and Clarks Fork rivers between Flathead Lake and Pend Oreille Lake is about 830 feet, of which over 800 feet is in Montana. The unregulated flow at the outlet of Flathead Lake varies from 1,450 to 75,000 second-feet, equivalent to 132,000 to 6,800,000 theoretical potential horse-power. The reservoir to be created in Flathead Lake to store flood water for use by the Columbia Basin Irrigation Project will have a beneficial effect on this potential power. The regulation of the stream, due to releasing in the late summer the water stored during the spring floods, will increase the low water flow, thereby more uniformly distributing the river's energy. If the stored water remaining in the lake at the end of the irrigating season is released during the winter months, when the normal low flow averages less than 2,500 second-feet, an increase in the potential power will result. Table No. 40 gives the minimum natural and regulated flows and the corresponding power, showing that in eight of the last thirteen years a substantial addition to the low water power would have been made.

Table No. 40.

POWER POSSIBILITIES, FLATHEAD LAKE TO MONTANA-IDAHO STATE LINE.

YEAR	Minimum Natural Flow	Power from Minimum Natural Flow	Minimum Flow Under Columbia Basin Regulation	Power from Minimum Flow Columbia Basin Regulation
	Second-feet	H. P.	Second feet	H. P.
1908	2,280	209,090	3,130*	286,690
1909	2,530	232,010	2,530	232,010
1910	3,640	333,800	3,640	333,800
1911	2,690	246,690	2,960*	271,440
1912	2,310	211,840	3,000*	275,120
1913	2,790	255,860	3,230*	296,210
1914	2,690	246,690	4,050*	371,400
1915	2,310	211,840	2,490*	228,340
1916	3,010	276,030	3,010	276,030
1917	2,000	183,410	2,340*	214,590
1918	2,510	230,180	2,560*	234,770
1919	2,075	190,290	2,075	190,290
1920	1,450	132,970	1,450	132,970

* Minimum flow and theoretical power increased.

To obtain complete regulation of the Flathead flow would require storing in the lake to elevation 2,907, which is 14 feet higher than the elevation proposed for the Columbia Basin Project. Such storage would yield a constant flow throughout the year of not less than 10,000 second-feet, theoretically equivalent to 917,000 continuous horse-power.

The amount of energy that can be developed will depend upon the nature and location of the available sites along the two rivers. The survey and study of power sites were not a part of the work which this commission was authorized to do. However, enough data are available to show that any regulation of Flathead Lake will increase the value of the flow for power purposes.

Appendix G.

RECAPITULATION OF PEND OREILLE SUPPLY ESTIMATES.

The estimates in the preceding portions of this report include all the larger items of expense necessary in constructing works to convey water from the Pend Oreille and Flathead sources to the Columbia Basin lands. No useful purpose would be served by publishing the more detailed figures, which fill several hundred pages of typewritten manuscript. These figures are accessible to those interested at the Commission's office in Spokane and at the office of the State Hydraulic Engineer in Olympia.

For convenience of reference, the estimates are here summarized, the items being arranged in sequence, starting at Flathead Lake and following the line of flow through the North, Central, and South divisions. The last table is a recapitulation of all, including the charges which are not readily segregated into the geographical divisions.

Table No. 41.

RECAPITULATION OF ITEMS OF MAIN SUPPLY CANAL.

ITEM	Cost	Contingencies
(1) Dam at Flathead Lake	$523,933	$30,000
Flathead Lake overflow rights	1,537,000	
(2) Dam at Pend Oreille Lake	731,868	35,000
Pend Oreille Lake overflow rights	428,000	
Head Gates	415,841	25,000
(3) Newport Tunnel	16,736,371	1,657,884
(4) Canal, Newport Tunnel to Chain Lakes	2,216,134	175,000
(5) G. N. Ry. Change	2,543,353	200,000
(6) Camden Dam	1,357,788	80,000
(7) Canal, Camden Dam to Hillcrest	23,973,725	1,378,000
(8) Dry Creek Dam	1,109,905	40,000
(9) Milan Tunnel	7,797,042	771,368
(10) Deep Creek Tunnel	3,509,726	347,095
(11) Deep Creek Dam	696,807	35,000
(12) Road changes at Deadman Creek and Deep Creek Lakes	138,000	
(13) Deadman Creek Tunnel	4,910,888	485,929
(14) Deadman Creek Dam	3,644,747	160,000
(15) Pleasant Prairie Tunnel	9,176,690	907,258
(16) Spokane River Crossing	1,217,539	50,000
(17) S. & I. Ry. Crossing	35,950	
(18) S. & I. E. R. R. Crossing	45,700	
(19) N. P. Ry. Crossing	166,960	
(20) C., M. & St. P. Ry. Crossing	34,585	
(21) Appleway Crossing	7,218	
(22) S. T. Co.—Vera Line Crossing	25,016	
(23) Street Crossings	56,219	
(24) Manito Tunnel	9,674,209	953,871
(25) Latah Creek Dam	2,337,754	150,000
(26) Bonnie Lake Tunnel	41,932,405	4,148,761
(27) Bonnie Lake Highway Bridge	4,818	
(28) Rock Lake Dam	2,307,471	100,000
(29) Wassun Creek Siphon	769,588	13,000
(30) Emergency wasteway (Wassun Creek)	641,091	
(31) Dragoon Lake Dam	16,059	1,600
(32) S., P. & S. Ry. Crossing	34,680	
(33) McCall Dam and Dike	376,402	25,000
(34) Patterson Tunnel	2,273,359	224,985
(35) O.-W. R. & N. Ry. Crossing	142,700	
(36) Cow Creek Siphon	2,423,286	46,000
(37) Hillcrest Siphon and Gates	654,718	12,000
(38) Drainage culverts, Albany Falls to Hillcrest	9,520	
(39) Fences	106,200	
(40) Telephone lines	91,200	
(41) Lateral "M1"	168,639	23,000
	$147,000,604	$12,075,751
Grand Total		$159,076,355

Excluding general items in Table No. 45.

Table No. 42.

RECAPITULATION OF ITEMS OF NORTH DIVISION.

ITEM	Cost	Contingencies
(1) Canal, Hillcrest to Ephrata	$19,281,393	$1,046,160
(2) McElroy Tunnel	1,858,848	183,864
(3) Paha Tunnel	453,508	44,845
(4) Paha Siphon	600,366	9,000
(5) Klemmer Tunnel	4,600,231	455,175
(6) Branch of Third Coulee Siphon	415,785	7,000
(7) Second Coulee Siphon	1,299,381	20,000
(8) Flaig Siphon	622,022	12,000
(9) First Coulee Siphon	966,464	10,000
(10) Sand Coulee Siphon	976,526	23,000
(11) Black Rock Coulee Siphon	814,829	14,000
(12) Broken Rock Coulee Siphon	1,747,607	24,000
(13) Round Lake Siphon	651,242	8,000
(14) Round Lake Flume	149,741	1,000
(15) Adrian Siphon	3,020,136	42,000
(16) Soap Lake Siphon	3,947,872	61,000
(17) Canals, Main from Ephrata to end of line, and all laterals	5,687,208	705,560
(18) G. N. Ry. Crossing, west of Quincy	114,126	....
(19) Potholes Siphon	1,461,016	26,000
(20) Frenchman Siphon	856,676	17,000
(21) Low Gap Tunnel	844,624	83,250
(22) Babcock Siphon, lateral N94	391,200	8,000
(23) Laterals, Hillcrest to Ephrata	2,669,046	72,300
(24) Siphon No. 1, lateral “N1”	12,970	150
(25) Siphon No. 2, lateral “N1”	14,355	100
(26) Siphon No. 3, lateral “N1”	15,665	100
(27) Chute, lateral “N22”	31,212	1,500
(28) Flume, lateral “N24”	32,026	....
(29) Siphon, lateral “N5”	158,041	2,000
(30) Ephrata Siphon, lateral “N6”	284,006	3,000
(31) Chute, lateral “N7”	24,237	1,000
(32) Road Crossings	192,244	....
(33) Fences	343,800	....
(34) Telephones	234,000	....
	$54,772,403	$2,881,004
Grand Total	....	$57,653,407

Excluding general items in Table No. 45.

Table No. 43.
RECAPITULATION OF ITEMS OF CENTRAL DIVISION.

ITEM	Cost	Contingencies
(1) Dam at diversion of Central and South Divisions, costing $171,900 with a contingency of $8,200, charged in proportion to relative capacities of canals, 58.6 per cent.	$100,585	$5,000
(2) Canal, Main line and laterals	16,500,825	655,750
(3) Tunnel, Providence Main "CC"	593,732	58,764
(4) Tunnel No. 1, Providence Main "CD"	653,497	64,641
(5) Dam, Providence Main "CD"	52,051	2,000
(6) Tunnel No. 2, Providence Main "CD"	271,036	26,800
(7) Siphon, Providence Coulee	490,799	7,000
(8) Chute, Providence-Shano Main "CE"	81,216	3,500
(9) Chute, Shano Main "CF"	55,097	2,000
(10) Crossing of Connell Northern Ry.	13,910	...
(11) Drop, Shano Main "CG"	10,956	...
(12) Siphon, Shano Main "CG"	1,053,494	15,600
(13) Siphon, Skootenay Springs, Shano Main "CG"	1,202,256	20,000
(14) Chute, Saddle Mountains, Main "CL"	10,195	400
(15) Chute, lateral "C54"	21,307	900
(16) Chute, lateral "C56"	41,511	1,900
(17) Drop No. 1, lateral "C7"	18,040	...
(18) Drop No. 2, lateral "C7"	16,480	...
(19) Chute, lateral "C72"	19,140	750
(20) Siphon, lateral "C72"	68,655	1,000
(21) Drop, lateral "C72"	15,979	...
(22) Chute, lateral "C77"	28,774	1,250
(23) Siphon, lateral "C781"	207,415	1,000
(24) Siphon, lateral "C8"	173,990	2,000
(25) Siphon, lateral "C82"	48,160	200
(26) Chute, lateral "C9"	38,209	1,750
(27) Chute, lateral "C92"	14,692	650
(28) Chute, lateral "CJ1"	46,069	2,000
(29) Road Crossings	128,609	...
(30) Fences	262,800	...
(31) Telephones	175,200	...
	$22,414,679	$874,255
Grand Total	...	$23,288,934

Excluding general items in Table No. 45.

Table No. 44.

RECAPITULATION OF ITEMS OF SOUTH DIVISION.

ITEM	Cost	Contingencies
(1) Dam at diversion of Central and South Divisions, costing $171,900 with a contingency of $8,200, charged in proportion to relative capacities of canals, 41.4 per cent	$71,315	$3,200
(2) Canal, South Main and laterals, Hillcrest to end of line	10,962,722	1,098,360
(3) South Main, Tunnel	1,118,193	110,607
(4) Drop, Snake River Main "SO"	17,975	1,200
(5) Kahlotus Siphon, Snake River Main "SE"	3,961,122	30,000
(6) Tunnel, Snake River Main "SF"	437,253	43,270
(7) Tunnel, Snake River Main "SG"	823,334	81,371
(8) Siphon, Snake River Main "SH"	257,885	5,000
(9) Tunnel, Snake River Main "SH"	148,546	14,702
(10) Snake River Siphon, Eureka Main "SJ"	5,050,770	86,500
(11) Tunnel No. 1, Eureka Main "SJ"	134,120	13,269
(12) Dam, Eureka Main "SJ"	53,150	5,000
(13) Tunnel No. 2, Eureka Main "SJ"	705,242	69,792
(14) Siphon, lateral "S41"	250,990	1,300
(15) Chute, lateral "S42"	16,524	700
(16) Chute, lateral "S74"	61,513	3,000
(17) Chute, lateral "S81"	37,480	1,750
(18) Chute No. 1, lateral "S82"	5,719	150
(19) Chute No. 2, lateral "S82"	31,037	1,450
(20) Chute, lateral "S83"	95,293	4,550
(21) Chute, lateral "S84"	112,252	5,350
(22) Siphon, lateral "S86"	73,520	400
(23) Siphon at foot of drop, lateral "S42"	238,730	5,000
(24) Road Crossings	124,109	....
(25) Fences	235,800	....
(26) Telephones	160,200	....
	$25,184,794	$1,585,921
Grand Total	....	$26,770,715

Excluding general items in Table No. 45.

Table No. 45.

RECAPITULATION OF ALL DIVISIONS.

ACCOUNT	Cost	Contingencies	Totals
Supply Canal (a)	$147,000,604	$12,075,751	$159,076,355
North Division (b)	54,772,403	2,881,004	57,653,407
Central Division (b)	22,414,679	874,255	23,288,934
South Division (b)	25,184,794	1,585,921	26,770,715
UNDISTRIBUTED ITEMS			
Distribution system below 100 second-feet capacity	26,295,000	....	26,295,000
Spillways and wasteways below Hillcrest	1,798,111	88,143	1,886,254
Minor wasteways on distribution system	500,000	....	500,000
Lateral headgates	384,013	19,200	403,213
General incidentals and miscellaneous items, including patrol houses	750,000	....	750,000
General engineering, administration and legal expense, preceding construction	1,051,800	....	1,051,800
Administration, legal and general expense, during construction	2,800,000	....	2,800,000
Totals	$282,951,404	$17,524,274	$300,475,678

(a) Includes lateral "M1".

(b) Road crossings totaling $444,962, divided among the three divisions.

APPENDIX H.

COLUMBIA RIVER PUMPING PROJECT.

General. The Columbia River Pumping Project contemplates returning 16,500 second-feet of the flow of the Columbia River into its prehistoric channel, the Grand Coulee, and from the lower end of the Coulee distributing the water over a portion of the Columbia Basin area. Since the present channel of the Columbia River is 600 feet below the floor of Grand Coulee, it would be necessary to raise the water that distance either by a dam, pumps, or a combination of the two. Field surveys and office studies were made on each of these plans.

The construction of a dam to create a gravity flow through Grand Coulee was determined to be impracticable. Such a dam would create a lake having a surface elevation of 1,552.5 feet above sea level. The overflow damages and international complications would make such a development practically out of reason. The elevation of the Columbia River at the international boundary would be increased 200 feet, raising the water surface 170 feet through Arrow Lakes, and submerging towns and railways. The power developments on the Spokane River at elevations of 1,373 and 1,527 would be submerged.

The dam would be over 600 feet in height with a crest length of 4,850 feet. Such a structure would require several years for completion and during flood periods in the river it might be necessary to pass 1,000,000 second-feet of water, introducing serious construction difficulties.

The construction of a dam of such dimensions in a river as large as the Columbia, even on an ideal foundation, appears to be highly impracticable, if not altogether impossible.

Studies made on pumping schemes indicate that the most satisfactory plan would be to construct a dam in the Columbia River at the head of the Grand Coulee having sufficient height to develop power for pumping. The pumping plant would consist of hydraulic turbines direct-connected to centrifugal pumps.

This dam should be as low as possible to prevent overflow damages and provide a spillway for flood waters. From the flow in the river during the irrigation season it has been determined that a dam 180 feet in height above the level of

the average low water would develop sufficient power for direct pumping.

In the event that foundation conditions render construction of a dam at this point infeasible, three alternate plans suggest themselves, each, however, having undesirable features.

1st. A dam farther up the river.
2nd. A dam farther down the river.
3rd. Independent power from some outside source.

Consider these alternate plans in the above order. If a dam were constructed farther up the river, it would be necessary to construct a very expensive supply canal along the rough, broken, steep slopes of the Columbia to convey the water from the dam to Grand Coulee, or place the pumping plant at Grand Coulee.

The pumping plant if placed at Grand Coulee would operate under a pressure head of approximately 600 feet. From a mechanical standpoint this would involve a serious complexity of design. It would be necessary to generate and transmit electric power to motor-driven pumps. This would require a dam 187 feet above present water surface and a plant having an installed capacity of 1,845,000 horse power.

A dam below Grand Coulee, if not too far distant, would create back water at Grand Coulee and decrease the pumping lift, but the water available for producing power for the pumps would be decreased by the irrigation demand. If direct-connected pumps were placed at the dam, the same difficulty of conveying the water along the Columbia slopes from the dam to Grand Coulee presents itself. The height of dam necessary for the generation of electric power would vary from 180 to 230 feet, depending upon whether or not back water occurred at Grand Coulee.

If it proved infeasible to construct a dam at or within reasonable distance of Grand Coulee, it would then be necessary to secure power from an outside source from plants having an installed capacity of 1,845,000 horse power.

(1) *Area of Land Covered.* The irrigable lands under this plan are in two groups, the Quincy area of 385,000 acres under the West Canal and the east side area of 1,018,000 acres under the East Canal. Map No. VII shows these areas and the canals supplying them.

(2) *Water Requirement for Land.* Using the water duty and the classification of the lands as determined for the Pend Oreille supply, it was found that 13,305 second-feet of water

would be required on the land, and to provide for regulatio and other losses, a gross diversion of 16,620 second-feet woul be necessary.

(3) *Water Available.* Gaugings have been taken fo many years at numerous places on the Columbia River. Fro these it is possible to determine very closely the flow at th entrance of the Grand Coulee. The minimum flow during th irrigation season, April to October, varies from about 26,40 second-feet to 31,000 second-feet. In years of normal flo the April and October minima average over 50,000 second-feet. During the time of maximum irrigation demand, th flow of the river is several hundred thousand second-fee The drainage area above the entrance to the Grand Coule exceeds 74,000 square miles. Numerous tributaries ente Columbia River between this place and The Dalles and it i not probable that the diversion required would adversel affect navigation.

(4) *Columbia River Dam.* The point of great uncertainty is the matter of foundations for the dam. The Columbia River in this locality is bordered by gravel terraces o both banks of the stream, the larger one here being on th north bank. Outcrops of granite are found on both sides o the river at elevations of 150 feet or more above the rive level. There is no question but that a dam with a height o 180 feet could be anchored to the granite at both ends, a least as far as the crest line is concerned. The problem therefore, is the depth below the river bed to the granite a a foundation for a masonry dam.

In the section of the Columbia from the mouth of the Wenatchee River to the international boundary, there are only one or two instances of bed rock occurring as the bed of the stream. Throughout this long section of the river, the stream is running for the most part over great deposits of boulders, gravels, sands, and other wash materials. At the close of the Glacial Period, the channel of the Columbia was clogged with debris to a height of several hundred feet above the rock floor of the valley. While much of this glacial sediment has now been carried away, a considerable portion yet remains and the river is in the main spending its energies in the removal of the glacial debris and is not working upon the bed rock. It is very clear that in the stretch of the river at the head of Grand Coulee, the Columbia has the old glacial deposit and not the granite rock for its bed.

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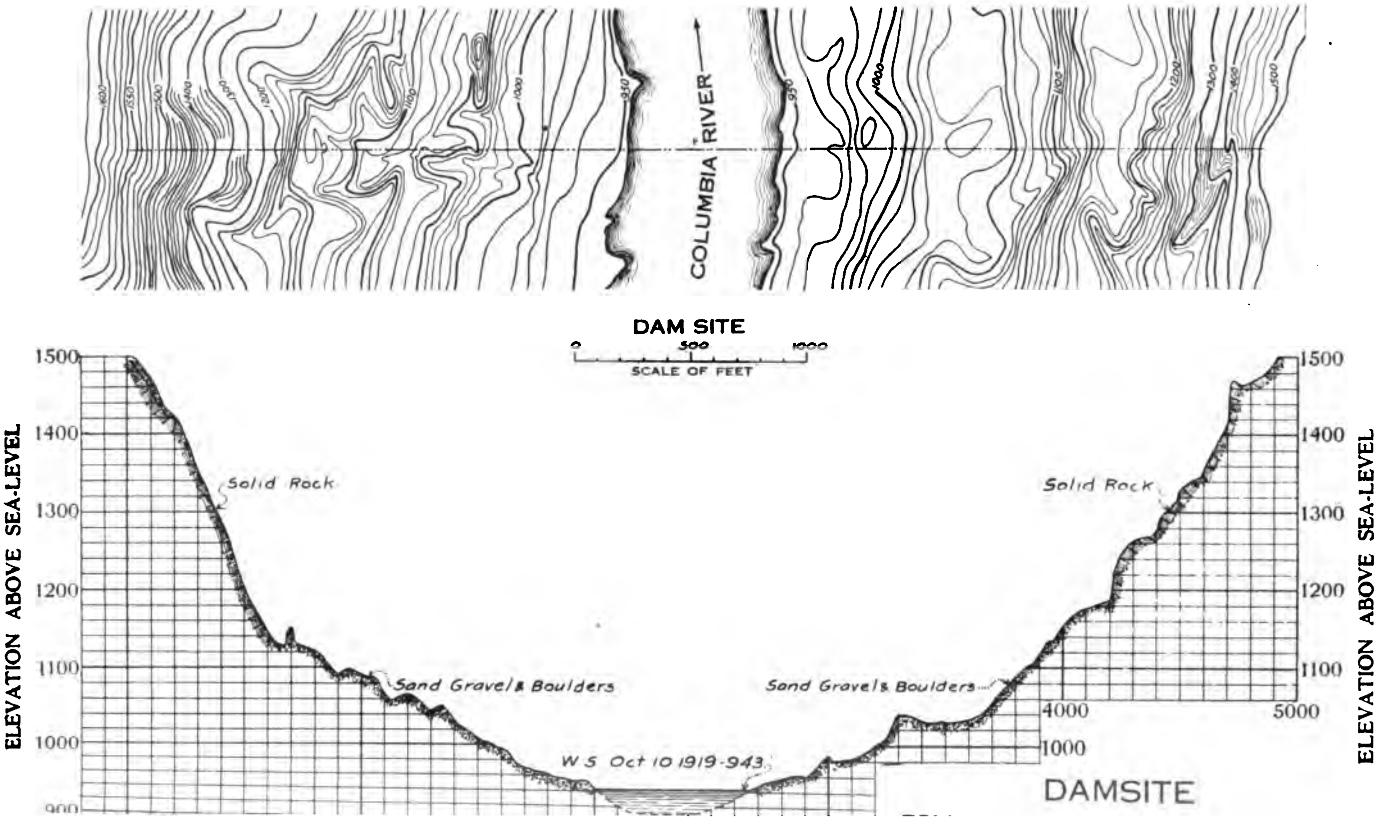COLUMBIA RIVER
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Another distributing canal would pass near Adrian and Wilson Creek, run southward nearly twenty miles and thence to the southeast. The distributing system from this canal is the same as the lower portion of the distribution system designed for the Pend Oreille supply.

Under this plan an area consisting of 350,000 acres of land lying from Hillcrest west to Ruff and south to Weber, Roxboro, Cunningham and Connell, including some choice land west of Cunningham, would be left without water. This area could not stand the burden of bringing an independent water supply from the Pend Oreille River, and would therefore be cut off from any practical possibility of ever being watered.

The wasteway and secondary storage opportunities on the east side of the pumping project are much inferior to the corresponding opportunities under the Pend Oreille supply. On the west side, the wasteway facilities are the same as under the Pend Oreille supply.

(7) *Summary of Estimated Costs.* The following tables state the dimensions, quantities of materials, and estimated costs of the principal structures required to convey water from the upper end of Grand Coulee to the farm laterals. The unit costs and methods of estimating quantities and costs are the same as were fully described in discussing the Pend Oreille supply. That discussion should be read in connection with the estimates of the Columbia River Pumping Project.

Table No. 47 — COST OF DAMS.

ITEM	Unit	Unit Cost	GRAND COULEE DAM		COULEE CITY DAM		BACON DAM		TOTALS	
			Quantity	Amount	Quantity	Amount	Quantity	Amount	Quantity	Amount
Earth excavation	Cu. Yd.	$0.25	19,020	$4,755	26,200	$6,550	3,500	$875	48,720	$12,180
Loose rock	Cu. Yd.	.60	1,500	900					1,500	900
Solid rock	Cu. Yd.	1.20	500	600					500	600
Solid rock trenching	Cu. Yd.	2.00			3,300	6,600	1,200	2,400	4,500	9,000
Rock fill	Cu. Yd.	.90	166,270	149,643	380,000	342,000	169,600	152,640	715,870	644,283
Hydraulic earth fill	Cu. Yd.	.50	69,000	34,500					69,000	34,500
Preparation rock facing	Sq. Yd.	.30			28,700	8,610	11,700	3,510	40,400	12,120
Concrete facing, light reinf.	Cu. Yd.	18.00			3,500	63,000	2,800	50,400	6,300	113,400
Gravel road on crest	Cu. Yd.	.75					3,700	2,775	3,700	2,775
Engineering				5,000		8,000		5,000		18,000
Contingencies				10,000		16,000		10,000		36,000
Totals				$205,398		$450,760		$227,600		$883,758

Table No. 48.

RECAPITULATION OF DAM QUANTITIES ALONG CANAL SYSTEM

LOCATION	Type	Length of Crest	Crest Height Above Foundation	Max-Depth of Water	Cu. Yds. in Structure	Cost
		Feet	Feet	Feet		
Grand Coulee	Rock and earth fill	1,120	80	70	185,270	$205,398
Coulee City	Rock fill	7,400	52	44	383,500	450,760
Bacon	Rock fill	2,600	60	52	172,400	227,600
Totals					741,170	$883,758

Table No. 49 — COST OF CANALS.

ITEM	Unit	Unit Cost	MAIN SUPPLY, COLUMBIA RIVER TO BACON LAKE		EAST MAIN COMPLETE		WEST MAIN COMPLETE		TOTALS	
			Quantity	Amount	Quantity	Amount	Quantity	Amount	Quantity	Amount
Right of Way	Acre	$150.00	80	$12,000					80	$12,000
Right of Way	Acre	70.00			64	$4,480			64	4,480
Right of Way	Acre	30.00			3,782	113,460	1,571	$47,130	5,353	160,590
Right of Way	Acre	25.00			190	4,750			190	4,750
Right of Way	Acre	20.00			200	4,000			200	4,000
Right of Way	Acre	15.00					262	3,930	262	3,930
Right of Way	Acre	10.00			94	940			94	940
Right of Way	Acre	7.50	447	3,353	268	2,011	12	90	727	5,454
Earth excavation	Cu. Yd.	.20	332,000	66,400	17,828,330	3,565,666	4,555,290	911,058	22,715,620	4,543,124
Loose rock and hardpan excavation	Cu. Yd.	.60			2,711,680	1,627,008	334,320	200,592	3,046,000	1,827,600
Solid rock excavation	Cu. Yd.	1.20	1,319,000	1,582,800	5,481,900	6,578,280	698,420	838,104	7,499,320	8,999,184
Concrete lining	Cu. Yd.	16.00	57,250	916,000	1,956,467	31,303,472	472,667	7,562,672	2,486,384	39,782,144
Reinforcing steel	Pound	.06	930,000	55,800	27,288,450	1,637,307	8,262,640	495,758	36,481,090	2,188,865
Road crossing steel	Pound	.09	35,500	3,195					35,500	3,195
Road crossing concrete	Cu. Yd.	15.00	60	900					60	900
Hand placed rock on slopes	Sq. Yd.	1.00					36,000	36,000	36,000	36,000
Dry rock wall	Cu. Yd.	5.00					9,900	49,500	9,900	49,500
Engineering				26,570		932,970		278,900		1,238,440
Contingencies				288,450		5,317,090		856,450		6,461,990
Totals				$2,955,468		$51,091,434		$11,280,186		$65,327,088

Table No. 50 — RECAPITULATION OF CANAL QUANTITIES

LOCATION	Length in Feet	Slope in Feet per 1,000 Feet	Velocity in Feet per Second	Capacity in Second-Feet		Excavation Cu. Yds.	Concrete Lining Cu. Yds.	Cost
				From	To			
MAIN CANAL—								
From Columbia River to Bacon Lake..........	26,100	0.50	12.3 to 12.2	16,730	16,730	1,651,000	57,250	$2,955,468
WEST CANAL—								
Quincy Main	227,895	0.19 to 1.00	5.2 to 12.1	4,640	1,990	3,006,060	160,572	
Babcock Main	273,300	0.19 to 5.59	3.7 to 11.7	1,190	235	1,705,000	170,561	
Laterals	605,800	0.19 to 11.93	2.5 to 12.5	830	100	876,970	141,534	
						5,588,030	472,667	11,280,186
EAST CANAL—								
Bacon Lake to Snake River......................	565,115	0.30 to 2.00	6.5 to 11.7	11,825	2,200	17,300,000	942,760	
Eureka Main	77,088	0.47 to 2.00	6.8 to 11.7	1,700	1,455	554,963	42,241	
Laterals	1,096,936	0.20 to 15.00	2.5 to 12.5	1,145	100	8,166,947	971,466	
						26,021,910	1,956,467	51,091,434
Totals..................................	2,872,234 ft. =543.98 miles	....	....	....	....	33,260,940	2,486,384	$65,327,088

Table No. 51 — COST OF TUNNELS.

TUNNEL	RIGHT OF WAY			EXCAVATION			LINING		Engineering	Contingencies	Totals
	Acres	Unit Cost	Amount	Cu. Yds.	Unit Cost	Amount	Cu. Yds.	Amount at $15 per Cu. Yd.			
Bacon	......	....	....	616,548	$5.58	$3,440,338	94,736	$1,421,040	$48,610	$486,140	$5,396,128
Long Lake No. 1	4	$7.50	$30	86,330	6.06	523,160	13,314	199,710	7,230	72,290	802,420
Long Lake No. 2	1	7.50	8	31,525	6.06	191,042	4,862	72,930	2,640	26,400	293,020
Long Lake No. 3	2	7.50	15	41,225	6.06	249,824	6,358	95,370	3,450	34,520	383,179
Stratford	10	7.50	75	207,580	6.06	1,257,935	32,014	480,210	17,380	173,810	1,929,410
Black Rock	7	7.50	52	131,490	5.33	700,842	18,960	284,400	9,850	98,520	1,093,664
Providence	33	10.00	330	495,030	5.58	2,762,267	75,400	1,131,000	38,930	389,330	4,321,857
Reeder	9	10.00	90	82,280	6.06	498,617	13,200	198,000	6,970	69,660	773,337
Delany No. 1	4	10.00	40	31,194	6.30	196,522	5,040	75,600	2,720	27,210	302,092
Delany No. 2	5	10.00	50	27,363	7.03	192,362	4,662	69,930	2,620	26,230	291,192
Delany No. 3	5	10.00	50	27,363	7.03	192,362	4,662	69,930	2,620	26,230	291,192
Delany No. 4	3	10.00	30	17,200	7.03	120,916	2,930	43,950	1,650	16,490	183,036
Eureka Main "SJ" No. 1	1	30.00	30	12,030	8.00	96,240	2,430	36,450	1,400	13,269	147,389
Eureka Main "SJ" No. 2	4	30.00	120	63,184	8.00	505,472	12,830	192,450	7,200	69,792	775,034
Quincy Main No. 1	3	7.50	23	21,563	6.30	135,847	3,563	53,445	1,890	18,930	210,135
Quincy Main No. 2	3	7.50	23	18,975	6.30	119,543	3,135	47,025	1,670	16,660	184,921
Quincy Main No. 3	5	7.50	38	34,500	6.30	217,350	5,700	85,500	3,030	30,290	336,208
Low Gap	4	30.00	120	77,900	7.76	604,504	15,200	228,000	12,000	83,250	927,874
Totals	103		$1,124	2,023,280		$12,005,143	318,996	$4,784,940	$171,860	$1,679,021	$18,642,088

Table No. 52 — RECAPITULATION OF TUNNEL QUANTITIES.

NAME	Length in Feet	Diameter Ft. In.	No. of Bores	Slope in Feet per 1,000 Feet	Cu. Yds. Excavation per Lin. Ft.	Cu. Yds. Concrete Lining per Lin. Ft.	Capacity Second-Feet One Bore	Average Cost per Lin. Ft. One Bore	Cost
Bacon	9,550	30′ 7″	2	0.85	32.28	4.96	8,434	$282.52	$5,396,128
Long Lake No. 1	1,780	26′ 5″	2	0.90	24.25	3.74	5,923	225.40	802,420
Long Lake No. 2	650	26′ 5″	2	0.90	24.25	3.74	5,923	225.40	293,020
Long Lake No. 3	850	26′ 5″	2	0.90	24.25	3.74	5,923	225.40	383,179
Stratford	4,280	26′ 5″	2	0.90	24.25	3.74	5,923	225.40	1,929,410
Black Rock	3,000	35′ 8″	1	0.60	43.83	6.32	10,890	364.55	1,093,664
Providence	14,500	31′ 6″	1	0.75	34.14	5.20	8,688	298.06	4,321,857
Reeder	4,000	24′ 4″	1	0.75	20.57	3.30	4,346	193.33	773,337
Delany No. 1	1,800	22′ 3″	1	0.75	17.33	2.80	3,403	167.75	302,092
Delany No. 2	2,100	19′ 3″	1	0.75	13.03	2.22	2,260	138.67	291,192
Delany No. 3	2,100	19′ 3″	1	0.75	13.03	2.22	2,260	138.67	291,192
Delany No. 4	1,320	19′ 3″	1	0.75	13.03	2.22	2,260	138.67	183,036
Eureka main "SJ" No. 1	1,500	15′ 0″	1	2.30	8.02	1.62	1,690	98.26	147,389
Eureka main "SJ" No. 2	7,920	15′ 0″	1	2.30	8.02	1.62	1,690	97.86	775,034
Quincy main No. 1	1,250	22′ 3″	1	1.60	17.25	2.85	4,640	168.10	210,135
Quincy main No. 2	1,100	22′ 3″	1	1.60	17.25	2.85	4,640	168.10	184,921
Quincy main No. 3	2,000	22′ 3″	1	1.60	17.25	2.85	4,640	168.10	336,208
Low Gap	9,500	15′ 0″	1	0.757	8.20	1.60	1,278	97.67	927,874
Totals	83,310 ft. =16.34 miles	....	....	....	....	....	....	....	$18,642,088

Table No. 53 — COST OF INVERTED SIPHONS.

LOCATION	RIGHT OF WAY			SIPHON STEEL		EXCAVATION FOR PIERS			CONCRETE IN PIERS		REINFORCED STEEL IN PIERS	
	Acres	Unit Cost	Amount	Pounds	Amount at 7c per Pound	Cu. Yds.	Unit Cost	Amount	Cu. Yds.	Amount at $15.00 per Cu. Yd.	Pounds	Amount at 6c per Pound
Crab Creek	20	$160.00	$3,200	39,174,540	$2,742,218	18,090	$0.50	$9,045	19,015	$285,225	265,320	$15,919
Broken Rock	30	7.50	225	42,970,130	3,007,909	36,670	3.00	80,010	31,680	475,200	387,300	23,238
Black Rock	15	7.50	113	16,693,116	1,168,518	12,512	3.00	37,536	13,192	197,880	163,200	9,792
First Coulee	28	25.00	700	41,676,360	2,917,345	31,400	.50	15,700	31,430	471,450	386,400	23,184
Weber Coulee No. 1.......	28	25.00	700	41,555,200	2,908,864	31,100	.50	15,500	31,100	466,500	388,800	23,328
Weber Coulee No. 2.......	20	30.00	600	31,796,000	2,225,720	22,656	.50	11,328	22,656	339,840	283,200	16,992
Lind Coulee	26	30.00	780	30,072,000	2,105,040	28,050	1.00	28,050	28,050	420,750	352,800	21,168
Cunningham	5	30.00	150	3,418,800	239,316	3,970	.50	1,985	3,970	59,550	50,400	3,024
Hatton	7	30.00	210	5,240,400	366,828	5,490	.50	2,745	5,490	82,350	69,600	4,176
Rattlesnake	4	30.00	120	2,767,500	193,725	3,490	.50	1,745	3,490	52,350	45,000	2,700
Washtucna	23	30.00	460	36,288,900	2,540,223	1,570	3.00	4,710	15,720	235,800	222,700	13,362
On lateral "N5"..........	5	30.00	150	1,750,000	122,500	7,920	1.00	7,920	1,000	15,000	....	....
On main "OG"............	8	30.00	240	11,892,666	832,486	7,618	1.00	7,618	8,580	128,700	112,500	6,750
Skootenay Springs	9	30.00	270	13,211,184	924,779	19,228	1.20	23,074	10,701	160,515	135,300	8,118
On lateral "C72".........	1	30.00	30	665,500	46,585	550	1.00	550	528	7,920	12,000	720
On lateral "C781"........	8	30.00	240	2,720,000	190,400	....	....	....	560	8,400	....	....
On lateral "C8"..........	5	30.00	150	2,078,000	145,460	....	....	....	1,242	18,630	....	....
On lateral "C82".........	2	30.00	60	600,000	42,000	....	....	....	120	1,800	....	....
On lateral "S41".........	10	30.00	300	3,240,000	226,800	....	....	....	876	13,140	....	....
Snake River	18	30.00	540	48,463,600	3,392,452	21,430	1.00	21,430	17,530	262,950	183,300	10,998
On lateral "S86".........	4	30.00	120	960,000	67,200	....	....	....	280	4,200	....	....
Dry Coulee	6	20.00	120	7,025,980	491,819	5,450	.50	2,725	4,750	71,250	13,130	788
Grand Coulee	23	15.00	345	35,015,000	2,451,050	2,620	.50	1,310	11,850	177,750	98,080	5,585
Potholes	11	30.00	330	24,936,264	1,745,538	23,925	1.00	23,925	20,880	313,200	243,600	14,616
Frenchman	8	30.00	240	10,236,270	716,539	13,182	1.00	13,182	11,458	171,870	134,355	8,061
On lateral "N94".........	4	30.00	120	4,230,000	296,100	3,960	1.00	3,960	4,716	70,740	63,000	3,780
On lateral "N6"..........	4	30.00	120	3,335,500	233,485	2,038	1.20	2,446	1,650	24,750	43,300	2,598
Total.............	332	....	$10,633	462,012,860	$32,340,899	302,919	....	$316,494	302,514	$4,537,710	3,648,285	$218,897

Table No. 53 — COST OF INVERTED SIPHONS — Concluded.

LOCATION	CONCRETE IN TRANSITIONS Heavy Reinforcement		CONCRETE IN TRANSITIONS Light Reinforcement		VALVES		Transportation	Special Items		Engineering	Contingencies	Totals
	Cu. Yds.	Amount at $27.00 per Cu. Yd.	Cu. Yds.	Amount at $19.00 per Cu. Yd.	No.	Amount at $500.00 Each						
Crab Creek								E$31,700	C$187,380	$82,270	$34,190	$3,391,147
Broken Rock										90,240	57,800	3,734,622
Black Rock										35,060	24,520	1,473,419
First Coulee										87,520	51,030	3,566,929
Weber Coulee No. 1										87,260	50,530	3,552,682
Weber Coulee No. 2								E 6,400	C 16,500	66,770	39,110	2,723,260
Lind Coulee								E 6,400	C 16,500	63,150	49,290	2,711,128
Cunningham										7,180	6,460	317,665
Hatton										11,000	8,930	476,239
Rattlesnake										5,810	5,680	262,130
Washtucna								E 4,625	C 51,030	76,210	30,950	2,957,370
On lateral "N5"	12	$324	113	$2,147	2	$1,000		M 5,000		4,000	2,000	160,041
On main "OG"	400	10,800	260	4,940	5	2,500	$32,500	F 1,000	X 960	25,000	15,000	1,068,494
Skootenay Springs					13	6,500	45,000	F 6,000		28,000	20,000	1,222,256
On lateral "C72"			400	7,600	2	1,000	3,250			1,000	1,000	69,655
On lateral "C781"					1	500	1,875			6,000	1,000	208,415
On lateral "C8"					1	500	5,250			4,000	2,000	175,990
On lateral "C82"					3	1,500	1,800			1,000	200	48,360
On lateral "S41"					1	500	3,250			7,000	1,300	252,290
Snake River	220	5,940	550	10,450	2	1,000		*	*	101,700	86,500	5,137,270
On lateral "S86"										2,000	400	78,920
Dry Coulee								X 1,800		14,750	7,660	590,912
Grand Coulee										73,530	18,460	2,728,030
Potholes	400	10,800	500	9,500	3	1,500	46,250			52,370	37,200	2,255,229
Frenchman					3	1,500	107,500			21,500	19,310	1,059,702
On lateral "N94"					1	500	7,000			9,000	8,000	399,200
On lateral "N6"	33	891	64	1,216	7	3,500		M 5,000	F 3,000	7,000	3,000	287,006
Totals	1,065	$28,755	1,887	$35,853	44	$22,000	$253,675	$1,586,605		$970,320	$581,520	$40,903,361

SPECIAL ITEMS

E—Railroad crossing excavation.
C—Railroad crossing concrete .
F—Preparation of footings.
X—Miscellaneous excavation.
Y—Excavation along siphon.
RS—Railroad crossing steel.

I—Bridge steel.
BC—Concrete in bridge piers.
PE—Excavation, footings shore piers.
C—Cofferdam, river piers.
M—Railroad traffic maintenance.

*Y— $4,325
E— 15,364
C— 5,880
RS — 14,013
I — 648,018

BC—$328,650
PE— 15,060
C— 210,000
M— 2,000

Table No. 54 — RECAPITULATION OF INVERTED SIPHON QUANTITIES.

LOCATION	Length in Feet	Maximum Head in Feet	No. of Pipes	Diameter of Pipes	Velocity Feet per Second	Capacity in Second-Feet	Weight of Steel in Pounds	Cost
MAIN CANAL—								
Crab Creek	5,565	258	4	17′ 0″	13.3	12,092	39,174,540	$3,391,147
Broken Rock	8,903	187	4	18′ 6″	11.0	11,828	42,970,130	3,734,622
Black Rock	3,419	115	4	18′ 0″	10.7	10,892	16,693,116	1,473,419
First Coulee	8,069	191	4	18′ 3″	10.5	10,988	41,676,360	3,566,929
Weber Coulee No. 1.	8,098	196	4	17′ 9″	10.2	10,100	41,555,200	3,552,682
Weber Coulee No. 2.	5,920	196	4	17′ 9″	10.2	10,100	31,796,000	2,723,260
Lind Coulee	7,516	165	4	17′ 6″	10.2	9,812	30,072,000	2,711,128
Cunningham	2,100	75	2	17′ 3″	10.0	4,674	3,418,800	317,665
Hatton	2,900	93	2	17′ 3″	10.0	4,674	5,240,400	476,239
Rattlesnake	1,845	80	2	16′ 9″	9.9	4,362	2,767,500	262,130
Washtucna	6,827	475	4	12′ 9″	8.3	4,240	36,288,900	2,957,370
DISTRIBUTION SYSTEM—								
Lateral "N5"	10,000	50	2	4′ 4″	13.0	384	1,750,000	160,041
Shano "CG"	13,200	190	1	12′ 3″	16.45	1,939	11,892,666	1,068,494
Skootenay Springs..	15,400	328	1	12′ 9″	14.5	1,852	13,211,134	1,222,256
Lateral "C72"	1,210	125	2	7′ 0″	17.9	1,362	665,500	69,655
Lateral "C781"	16,000	125	1	4′ 2″	6.9	100	2,720,000	208,415
Lateral "C8"	9,200	130	1	5′ 6″	12.6	300	2,078,000	175,990
Lateral "C82"	4,000	100	1	3′ 8″	10.4	110	600,000	48,360
Lateral "S41"	18,000	180	1	4′ 6″	6.9	110	3,240,000	252,290
Snake River	17,680	690	3	8′ 9″	9.3	1,672	48,463,600	5,137,270
Lateral "S86"	6,000	130	1	4′ 0″	8.0	100	960,000	73,920
Dry Coulee	2,536	242	2	15′ 6″	12.3	4,660	7,025,980	590,912
Grand Coulee	9,942	356	2	14′ 9″	11.96	4,888	35,015,000	2,728,030
Potholes	21,760	190	1	16′ 0″	9.76	1,980	24,986,264	2,218,029
Frenchman	12,680	149	1	15′ 3″	9.45	1,750	10,286,270	1,040,392
Babcock	9,000	50	1	10′ 0″	7.1	558	4,230,000	399,200
Lateral "N6"	9,530	100	1	9′ 0″	13.8	876	3,335,500	287,006
Totals........	235,300	....	......	....	....	....	462,012,860	$40,903,361

Table No. 55 — MAIN SUPPLY, EXCLUSIVE OF COLUMBIA RIVER DAM.

ITEM	Amount	Contingencies	Total Amount
Overflow damages above Columbia River dam....	$1,000,000	....	$1,000,000
Pumping plant	25,680,781	$500,000	26,180,781
Railroad	450,000	....	450,000
Canal, Columbia River dam to Bacon Lake......	2,667,018	288,450	2,955,468
Grand Coulee Lake, both dams and overflow rights	871,158	26,000	897,158
Grand Coulee, outlet gates.......................	76,570	5,000	81,570
Bacon tunnel	4,909,988	486,140	5,396,128
Bacon dam	217,600	10,000	227,600
Bacon dam, outlet gates..........................	57,300	4,500	61,800
Totals....................................	$35,930,415	$1,320,090	$37,250,505

Table No. 56 — WEST MAIN CANAL.

ITEM	Amount	Contingencies	Total Amount
Canal, main and all laterals	$10,423,736	$856,450	$11,280,186
Quincy main, tunnel No. 1	191,205	18,930	210,135
Quincy main, tunnel No. 2	168,261	16,660	184,921
Quincy main, tunnel No. 3	305,918	30,290	336,208
Dry Coulee inverted siphon	583,252	7,660	590,912
Grand Coulee inverted siphon	2,709,570	18,460	2,728,030
Great Northern crossing west of Quincy	114,126	....	114,126
Potholes inverted siphon	2,218,029	37,200	2,255,229
Frenchman inverted siphon	1,040,392	19,310	1,059,702
Low Gap tunnel	844,624	83,250	927,874
Inverted siphon on lateral "N94" Babcock	391,200	8,000	399,200
Inverted siphon on lateral "N6"	284,006	3,000	287,006
Chute on lateral "N7"	24,237	1,000	25,237
Road crossings	78,134	....	78,134
Fences	188,370	....	188,370
Telephone lines	127,200	....	127,200
Totals	$19,692,260	$1,100,210	$20,792,470

Table No. 57 — EAST MAIN CANAL.

ITEM	Amount	Contingencies	Total Amount
Canal, main and all laterals	$45,774,344	$5,317,090	$51,091,434
Crossing of Washington Central Ry	10,572	750	11,322
Long Lake tunnel No. 1	730,130	72,290	802,420
Long Lake tunnel No. 2	266,620	26,400	293,020
Long Lake tunnel No. 3	348,659	34,520	383,179
Stratford tunnel	1,755,600	173,810	1,929,410
Crab Creek inverted siphon	3,356,957	34,190	3,391,147
Broken Rock inverted siphon	3,676,822	57,800	3,734,622
Black Rock inverted siphon	1,448,899	24,520	1,473,419
Black Rock tunnel	995,144	98,520	1,093,664
First Coulee inverted siphon	3,515,899	51,030	3,566,929
Weber Coulee inverted siphon No. 1	3,502,152	50,530	3,552,682
Weber Coulee inverted siphon No. 2	2,684,150	39,110	2,723,260
Lind Coulee inverted siphon	2,661,838	49,290	2,711,128
Providence tunnel	3,932,527	389,330	4,321,857
Cunningham inverted siphon	311,205	6,460	317,665
Hatton inverted siphon	467,309	8,930	476,239
Rattlesnake inverted siphon	256,450	5,680	262,130
Reeder tunnel	703,677	69,660	773,337
Washtucna inverted siphon	2,926,420	30,950	2,957,370
Delany tunnel No. 1	274,882	27,210	302,092
Delany tunnel No. 2	264,962	26,230	291,192
Delany tunnel No. 3	264,962	26,230	291,192
Delany tunnel No. 4	166,546	16,490	183,036
Inverted siphon on lateral "N5"	158,041	2,000	160,041
Crossing of Connell Northern Ry	13,910	....	13,910
Inverted siphon on main "CG"	1,053,494	15,000	1,068,494
Skootenay Springs inverted siphon	1,202,256	20,000	1,222,256
Inverted siphon on lateral "C72"	68,655	1,000	69,655
Inverted siphon on lateral "C781"	207,415	1,000	208,415
Inverted siphon on lateral "C8"	173,990	2,000	175,990
Inverted siphon on lateral "C82"	48,160	200	48,360
Inverted siphon on lateral "S41"	250,990	1,300	252,290
Reinforced concrete inverted siphon on lateral "S42"	238,730	5,000	243,730
Snake River inverted siphon	5,050,770	86,500	5,137,270
Tunnel, Eureka main "SJ" No. 1	134,120	13,269	147,389
Tunnel, Eureka main "SJ" No. 2	705,242	69,792	775,034
Dam on Eureka main "SJ"	53,150	5,000	58,150
Inverted siphon on lateral "S86"	73,520	400	73,920
Chutes and drops, entire main	584,396	23,750	608,146
Road crossings	308,491	....	308,491
Fences	540,900	....	540,900
Telephone lines	375,000	....	375,000
Totals	$91,537,956	$6,883,231	$98,421,187

Table No. 58 — RECAPITULATION, COLUMBIA RIVER PUMPING PROJECT.

ITEM	Amount	Contingencies	Total Amount
Overflow damages above Columbia River dam	$1,000,000		$1,000,000
Pumping plant	25,680,781	$500,000	26,180,781
Railroad, Coulee City to Columbia River damsite, 30 miles at $15,000 per mile, including salvage	450,000		450,000
Canal, Columbia River dam to Grand Coulee Lake	894,813	119,952	1,014,765
Grand Coulee Lake, overflow rights and dams at each end	871,158	26,000	897,158
Grand Coulee Lake, outlet gates	76,570	5,000	81,570
Canal, Grand Coulee to Bacon Lake	1,772,205	168,498	1,940,703
Bacon tunnel	4,909,988	486,140	5,396,128
Bacon dam	217,600	10,000	227,600
Bacon dam, outlet gates	57,300	4,500	61,800
Sub-total, Main Supply, excluding Columbia River Dam			$37,250,505
East main canal to Snake River, and laterals	83,483,807	6,467,240	89,951,047
Eureka main canal and laterals	8,054,149	415,991	8,470,140
West main canal through Quincy district, and laterals	19,692,260	1,100,200	20,792,470
Distribution system below 100 second feet capacity	21,045,000		21,045,000
Spillways and wasteways on main canals	722,743	49,600	772,343
Spillways and wasteways on laterals	400,000		400,000
Lateral headgates	463,218	23,161	486,379
General incidentals, miscellaneous items, including patrol houses	600,000		600,000
General engineering, administration, and legal expense preceding construction	841,800		841,800
Administration, legal, and general expense during construction	2,240,000		2,240,000
Totals	$173,473,392	$9,376,292	$182,849,684
Assuming feasible foundation, and that the river can be controlled during construction, Columbia River dam is estimated to cost from			$60,000,000
to			75,000,000
Total cost of project			$242,849,684
to			257,849,684

Cost per acre for 1,403,000 acres irrigated, $173.09 to $183.78.

(8) *Comparison With Pend Oreille Supply.* First. The needs of state and national development require the reclamation of the largest possible areas of land, and any project which leaves undeveloped an adjacent area which might have been included, is an economic loss.

Second. The cost per acre under the larger area would be no greater than under the smaller area.

Third. The reliability and simplicity of a direct gravity flow of water are immeasurably superior to the complexity of operating a power and pumping plant with a large number of turbines and pumps which would be stressed higher than any existing equipment of equal capacity.

Fourth. The annual operating and upkeep cost of the pumping plant would be much greater than the charges under the gravity system.

To these should be added the impracticability and perhaps impossibility of building a dam in the Columbia River near Grand Coulee or of securing sufficient power from any outside source. Every consideration indicates the superiority of the Pend Oreille gravity supply over the Columbia River pumping supply.

(9) *International Treaty Obligations.* The treaty* of August 5, 1846, between the United States and Great Britain, provides that navigation on the Columbia River from the international boundary to the ocean "shall be free and open to the Hudson's Bay Company and to all British subjects trading with the same * * * with free access into and through the said river or rivers, it being understood that all the usual portages along the line thus described shall, in like manner, be free and open."

This provision of the international treaty prohibits the construction of the proposed dam in the Columbia River unless locks are also constructed to pass navigation by the dam. The treaty is silent upon the size of vessels. This point would have to be determined probably by international convention before plans could be drawn and estimates made of the cost of the locks. It is apparent, however, that a flight of locks adequate to pass even small craft through a difference of elevations exceeding 180 feet would be exceedingly difficult to design and construct and would cost a very large sum of money. To create a new treaty covering the situation, or to abrogate the existing treaty, would delay the project possibly many years. The existence of the treaty in its present form practically eliminates further consideration of any plan requiring a high dam in the Columbia River.

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* "Treaty between the United States and Great Britain in regard to limits westwards of the Rocky Mountains," Article II, 1 Remington's and Ballinger's Annotated Codes and Statutes, page 17, 1910 edition.

APPENDIX I.

WENATCHEE LAKE-QUINCY PROJECT.

General. The possibility of using Wenatchee Lake as a storage reservoir and a source of supply for irrigating water for the large area of land lying east and south of Quincy, Winchester and Ephrata has been discussed for a number of years. Several preliminary reports have been made covering such development and some years ago the Quincy Valley Irrigation District was formed for the purpose of constructing the necessary works. Financial difficulties prevented the execution of these plans, although legislation was secured reserving a portion of the water of Wenatchee Lake for the use of the Quincy area.

The earlier studies were made available to this commission, but were not found as comprehensive as was desired by the commission. A field party was therefore sent to Wenatchee Lake and a detailed topographic and location survey was made from the lake to the district. The land classification and other studies within the district were covered in conjunction with the Pend Oreille supply study.

(1) *Area of Land Covered.* There are 410,000 acres which may be watered from the Wenatchee Lake. Of this area, 387,000 acres are in the Quincy Valley and 23,000 acres are on the Wenatchee and Columbia River slopes and in Moses Coulee. The area in the Quincy Valley consists of 241,000 acres class "A" land, 72,960 of class "B," and 73,040 of class "C." The discussion given on pages 24 to 27 concerning soils, classification and productivity of the Columbia Basin lands applies to the Quincy Valley area and need not be repeated here. The greater portion of the land lies in a very flat basin sloping southward from the Great Northern Railroad and drains into Moses Lake and Crab Creek.

With the full development of the irrigable lands and the maximum use of water, it will probably be necessary to construct a drainage system through the central portion of the area, leading into Crab Creek or the pothole region west of Crab Creek. Natural drainage exists through the Willow Spring Canyon, through the Frenchman Springs water course, and into the pothole country west of the irrigable area. These are fully discussed in Appendix D, "Drainage and Wasteways."

(2) *Water Requirement for Land.* These lands will require from two and one-half to three feet of water to sustain intensive diversified farming. The average requirement, however, will be about 33 acre-inches per acre. The percentages of water loss due to seepage, evaporation and regulation were assumed to be the same as on the Pend Oreille supply, five per cent in the main supply canals and fifteen per cent in the distribution system. Applying these figures to the net duty on the land, gives a gross duty or diversion requirement of 3.34 acre-feet per acre. This is equivalent to a seasonal demand of 1,314,960 acre-feet, and during the month of maximum use, a flow from the reservoir of 4,550 cubic feet per second.

The Great Northern Railroad Company has a power plant near Leavenworth, on the Wenatchee River, with a water right of 525 second-feet. In order to release a portion of this water from the power plant demand and make it available for irrigation, it is proposed to construct a power plant near Dryden in lieu of the existing plant near Leavenworth. The new plant will be supplied with 170 second-feet of water under a pressure head of 590 feet. This will supply the railroad with the same amount of power as can be generated in the present plant, using 525 second-feet under 187 feet head and release 355 second-feet for the use of the Quincy District.

The 170 second-feet of water discharged through the proposed new power plant, plus the flow entering Wenatchee River below the Wenatchee Lake dam and above the intake for the Wenatchee Irrigation District (*i. e.*, between mouth of Beaver Creek and Dryden) will be sufficient to supply that district, and all other existing rights on the Wenatchee River. There are a few short periods during which small amounts of water must be released from storage to supplement the flow available for the Wenatchee canals. The amounts are as follows:

Table No. 59 — WATER RELEASED FOR WENATCHEE CANAL.

October, 1911	102 second-feet,	equals 6,261 acre-feet.
September, 1912	52 second-feet,	equals 3,089 acre-feet.
October, 1912	116 second-feet,	equals 7,120 acre-feet.
October, 1917	48 second-feet,	equals 2,946 acre-feet.

Since these amounts are much less than the residue remaining in the reservoir in those years, they have been omitted from the demand shown in the table.

The figures given for "Combined Demand" therefore represent 170 second-feet continuous flow for the new power

plant, plus the Quincy irrigation demand for 410,000 acres at 3.34 acre-feet per season.

Table No. 60 — WATER REQUIRED FROM WENATCHEE LAKE.

MONTH	170 Second-Feet Prior Demand Acre-Feet	IRRIGATION DEMAND		Combined Demand Acre-Feet
		Per Cent. Each Month	Acre-Feet	
January	10,453			10,453
February	9,442*			9,442*
March	10,453	3.00	41,082	51,535
April	10,115	4.65	63,677	73,792
May	10,453	14.92	204,314	214,767
June	10,115	16.00	219,104	229,219
July	10,453	18.68	255,805	266,258
August	10,453	20.42	279,681	290,084
September	10,115	13.80	188,977	199,092
October	10,453	8.53	116,810	127,263
November	10,115			10,115
December	10,453			10,453
Totals	123,073	100.00	1,369,400	1,492,473

* 9,778 for leap years.
9,442 for other years.

(3) *Water Available From Wenatchee River.* Gagings of the flow of the Wenatchee River have been made from 1904 to the present time. While these readings were not all taken at the same place, they give a satisfactory record of the flow.

Gagings of river flow at places lower down the stream than the station near the mouth of Beaver Creek have been reduced on the basis of the relative drainage areas. The watershed above the Beaver Creek gage is 591 square miles.

The average annual demand upon the reservoir would be 1,492,000 acre-feet. The average flow of the stream during the 16 years since gagings were started has been 1,657,000 acre-feet, although during the year ending October 31, 1915, the flow was but 966,400 acre-feet. From the foregoing, it is apparent that the supply must be carefully conserved. The difference between the maximum demand of 4,720 second-feet and the natural flow of 766 second-feet during August, 1915, would be drawn from storage. Since the flow from July, 1914, to October, 1915, both inclusive, is less than the demand by 1,077,900 acre-feet, a storage of at least that amount must be provided.

Evaporation losses were estimated for all elevations of water surface and all months of the year, using the loss rates as determined on nearby Kachess Lake.* Surplus reservoir capacity has been estimated equal to the amount of evaporation from the maximum area of surface for a period of two years, and the evaporation loss has been neglected in computing the monthly demand on storage.

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* Uinted States Geological Survey, Water Supply Paper No. 486.

(4) *Storage Required.* Table No. 61 gives the reservoir capacity which can be created in Wenatchee Lake by erecting a dam on the Wenatchee River below the mouth of Beaver Creek. Table No. 62 presents a detailed study of the effect of a dam raising the water surface either 177 or 195 feet.

Table No. 61.

WENATCHEE LAKE STORAGE CAPACITY.

Dam below Beaver Creek.

Elevation of Water Surface	Total Area	Capacity Between Contours	Total Capacity	Elevation of Water Surface	Total Area	Capacity Between Contours	Total Capacity
	Acres	Acre-Feet	Acre-Feet		Acres	Acre-Feet	Acre-Feet
1,800	12	....	....	1,910	8,377	79,035	283,235
1,810	65	385	385	1,920	9,548	89,265	372,500
1,820	117	910	1,295	1,930	10,755	101,515	474,015
1,830	206	1,615	2,910	1,940	12,500	116,275	590,290
1,840	325	2,655	5,565	1,950	13,480	129,900	720,195
1,850	452	3,885	9,450	1,960	14,200	138,400	858,590
1,860	750	6,010	15,460	1,970	14,710	144,550	1,003,140
1,870	3,582	21,660	37,120	1,980	15,400	150,550	1,153,690
1,880	4,851	42,165	79,285	1,990	16,075	157,375	1,311,065
1,890	6,352	56,015	135,300	2,000	16,820	164,475	1,475,540
1,900	7,430	68,910	204,200				

Table No. 62.

WENATCHEE LAKE RUNOFF, DEMAND, AND STORAGE.

For dams storing 177 and 195 feet depth. Starting with full reservoir.
(All quantities in acre-feet.)

Year	MONTH	Runoff of Wenatchee River	Combined Demands	177-Foot Dam. In Storage	195-Foot Dam. In Storage
1904	August	92,100	290,084	910,541	1,195,316
	September	43,200	199,092	754,649	1,039,424
	October	37,400	127,263	664,786	949,561
	November	46,500	10,115	701,171	985,946
	December	52,100	10,453	742,818	1,027,593
1905	January	35,600	10,453	767,965	1,052,740
	February	35,900	9,442	794,423	1,079,198
	March	160,000	51,535	902,888	1,187,663
	April	166,600	73,792	995,696	1,280,471
	May	255,500	214,767	1,036,429	1,321,204
	June	390,000	229,219	1,108,525*	1,398,300*
	July	183,900	266,258	1,026,167	1,310,942
	August	69,000	290,084	805,083	1,089,858
	September	43,500	199,092	649,491	934,266
	October	128,500	127,263	650,728	935,503
	November	47,200	10,115	687,813	972,588
	December	38,700	10,453	716,060	1,000,835
1906	January	41,100	10,453	746,707	1,031,482
	February	55,000	9,442	792,265	1,077,040
	March	53,100	51,535	793,830	1,078,605
	April	207,500	73,792	927,538	1,212,313
	May	306,300	214,767	1,019,071	1,303,846
	June	200,300	229,219	990,152	1,274,927
	July	134,200	266,258	858,094	1,142,869
	August	51,400	290,084	619,410	904,185
	September	39,900	199,092	460,218	744,993
	October	105,900	127,263	438,855	723,630
	November	171,500	10,115	600,240	885,015
	December	56,900	10,453	646,687	931,462
1907	January	41,100	10,453	677,334	962,109
	February	81,500	9,442	749,392	1,034,167
	March	74,400	51,535	772,257	1,057,032
	April	165,500	73,792	863,965	1,148,740
	May	487,000	214,767	1,108,525*	1,393,300*
	June	352,500	229,219	1,108,525*	1,393,300*
	July	178,500	266,258	1,020,767	1,305,542
	August	69,000	290,084	799,683	1,084,458
	September	48,800	199,092	649,391	934,166
	October	48,400	127,263	570,528	855,303
	November	54,900	10,115	615,313	900,088
	December	69,100	10,453	673,960	958,735
1908	January	55,000	10,453	718,507	1,003,282
	February	45,400	9,778	754,129	1,038,904
	March	86,900	51,535	789,494	1,074,269
	April	161,200	73,792	876,902	1,161,677
	May	313,500	214,767	975,635	1,260,410
	June	426,500	229,219	1,108,525*	1,393,300*
	July	396,000	266,258	1,108,525*	1,393,300*
	August	91,500	290,084	909,941	1,194,716
	September	44,400	199,092	755,249	1,040,024
	October	63,700	127,263	691,686	976,461
	November	96,100	10,115	777,671	1,062,446
	December	59,600	10,453	826,818	1,111,593

* Denotes months in which there is a full reservoir and natural flow greater than the demand.

Table No. 62.

WENATCHEE LAKE RUNOFF, DEMAND, AND STORAGE—Continued.

Year	MONTH	Runoff of Wenatchee River	Combined Demands	177-Foot Dam. In Storage	195-Foot Dam. In Storage
1909	January	45,200	10,453	861,565	1,146,340
	February	44,600	9,442	896,723	1,181,496
	March	82,400	51,535	927,588	1,212,363
	April	175,600	73,792	1,029,396	1,314,171
	May	289,000	214,767	1,103,629	1,388,404
	June	505,000	229,219	1,108,525*	1,393,300*
	July	225,500	266,258	1,067,767	1,352,542
	August	66,800	290,084	844,483	1,129,258
	September	37,100	199,092	682,491	967,266
	October	45,500	127,263	600,728	885,503
	November	226,000	10,115	816,613	1,101,388
	December	166,000	10,453	972,160	1,256,935
1910	January	67,600	10,453	1,029,307	1,314,082
	February	52,200	9,442	1,072,065	1,356,840
	March	178,000	51,535	1,108,525*	1,393,300*
	April	274,000	73,792	1,108,525*	1,393,300*
	May	523,000	214,767	1,108,525*	1,393,300*
	June	309,000	229,219	1,108,525*	1,393,300*
	July	209,000	266,258	1,051,267	1,336,042
	August	79,900	290,084	841,083	1,125,858
	September	36,900	199,092	678,891	963,666
	October	123,000	127,263	674,628	959,403
	November	179,000	10,115	843,513	1,138,288
	December	60,800	10,453	893,860	1,188,635
1911	January	44,900	10,453	928,307	1,223,082
	February	32,000	9,442	950,865	1,245,640
	March	50,300	51,535	949,630	1,244,405
	April	124,000	73,792	999,838	1,294,613
	May	247,000	214,767	1,032,071	1,326,846
	June	359,000	229,219	1,108,525*	1,393,300*
	July	162,000	266,258	1,004,267	1,289,042
	August	60,300	290,084	774,483	1,059,258
	September	48,700	199,092	624,091	908,866
	October	34,700	127,263	531,528	816,303
	November	80,900	10,115	602,313	887,088
	December	56,900	10,453	648,760	933,535
1912	January	49,700	10,453	688,007	972,782
	February	48,100	9,778	726,329	1,011,104
	March	46,100	51,535	720,894	1,005,669
	April	135,000	73,792	782,102	1,066,877
	May	405,000	214,767	972,335	1,257,110
	June	386,000	229,219	1,108,525*	1,393,300*
	July	156,000	266,258	998,267	1,283,042
	August	66,400	290,084	774,583	1,059,358
	September	41,700	199,092	617,191	901,966
	October	38,000	127,263	527,928	812,703
	November	47,700	10,115	565,513	850,288
	December	47,400	10,453	602,460	887,235
1913	January	44,000	10,453	636,007	920,782
	February	48,200	9,442	674,765	959,540
	March	51,600	51,535	674,830	959,605
	April	127,000	73,792	728,038	1,012,813
	May	366,000	214,767	879,271	1,164,046
	June	562,000	229,219	1,108,525*	1,393,300*
	July	310,000	266,258	1,108,525*	1,393,300*
	August	103,000	290,084	921,441	1,206,216
	September	67,800	199,092	790,149	1,074,924
	October	76,900	127,263	739,786	1,024,561
	November	77,400	10,115	807,071	1,091,846
	December	51,000	10,453	847,618	1,132,393

* Denotes months in which there is a full reservoir and natural flow greater than the demand.

Table No. 62.

WENATCHEE LAKE RUNOFF, DEMAND, AND STORAGE—Continued.

Year	MONTH	Runoff of Wenatchee River	Combined Demands	177-Foot Dam. In Storage	195-Foot Dam. In Storage
1914	January	71,300	10,453	908,465	1,193,240
	February	37,000	9,442	936,023	1,220,798
	March	92,800	51,535	977,288	1,262,063
	April	203,000	73,792	1,106,496	1,391,271
	May	364,000	214,767	1,108,525*	1,393,300*
	June	271,000	229,219	1,108,525*	1,393,300*
	July	170,000	266,258	1,012,267	1,297,042
	August	60,300	290,084	782,483	1,067,258
	September	42,200	199,092	625,591	910,366
	October	58,400	127,263	556,728	841,503
	November	133,000	10,115	679,613	964,388
	December	54,900	10,453	724,060	1,008,835
1915	January	30,200	10,453	743,807	1,028,582
	February	23,900	9,442	758,265	1,043,040
	March	63,300	51,535	770,030	1,054,805
	April	216,000	73,792	912,238	1,197,013
	May	160,000	214,767	857,471	1,142,246
	June	111,000	229,219	739,252	1,024,027
	July	65,200	266,258	538,194	822,969
	August	47,000	290,084	295,110	579,885
	September	23,900	199,092	119,918	404,693
	October	38,000	127,263	30,655	315,430
	November	55,900	10,115	76,440	361,225
	December	36,200	10,453	102,187	386,972
1916	January	33,700	10,453	125,434	410,219
	February	42,400	9,778	158,056	442,841
	March	102,000	51,535	208,521	493,306
	April	184,000	73,792	318,729	603,514
	May	379,000	214,767	482,962	767,747
	June	558,000	229,219	811,743	1,096,528
	July	396,000	266,258	941,485	1,226,270
	August	159,000	290,084	810,401	1,095,186
	September	58,400	199,092	669,709	954,494
	October	29,800	127,263	572,246	857,031
	November	33,100	10,115	595,231	880,016
	December	25,100	10,453	609,878	894,663
1917	January	26,400	10,453	625,825	910,610
	February	33,500	9,442	649,883	934,668
	March	29,900	51,535	628,248	913,033
	April	54,300	73,792	608,756	893,541
	May	320,000	214,767	713,989	998,774
	June	478,000	229,219	962,770	1,247,555
	July	378,000	266,258	1,074,512	1,359,297
	August	107,000	290,084	891,428	1,176,213
	September	44,900	199,092	737,236	1,022,021
	October	31,800	127,263	641,773	926,558
	November	40,300	10,115	671,958	956,743
	December	224,000	10,453	885,505	1,170,290
1918	January	242,000	10,453	1,108,525*	1,393,300*
	February	69,400	9,442	1,108,525*	1,393,300*
	March	60,000	51,535	1,108,525*	1,393,300*
	April	171,000	73,792	1,108,525*	1,393,300*
	May	296,000	214,767	1,108,525*	1,393,300*
	June	400,000	229,219	1,108,525*	1,393,300*
	July	170,000	266,258	1,012,267	1,297,042
	August	65,800	290,084	787,983	1,072,758
	September	38,500	199,092	627,391	912,166
	October	57,600	127,263	557,728	842,503
	November	59,400	10,115	607,013	891,788
	December	121,000	10,453	717,560	1,002,335

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* Denotes months in which there is a full reservoir and natural flow greater than the demand.

Table No. 62
WENATCHEE LAKE RUNOFF, DEMAND, AND STORAGE.—Concluded.

Year	MONTH	Runoff of Wenatchee River	Combined Demands	177-Foot Dam. In Storage	195-Foot Dam. In Storage
1919	January	70,100	10,453	777,207	1,061,982
	February	48,200	9,442	815,965	1,100,740
	March	48,700	51,585	813,130	1,097,905
	April	179,000	73,792	918,338	1,203,113
	May	870,000	214,767	1,073,571	1,358,346
	June	385,000	229,219	1,108,525*	1,393,300*
	July	307,000	266,258	1,108,525*	1,393,300*
	August	105,000	290,084	923,441	1,208,216
	September	45,200	199,092	769,549	1,054,324
	October	28,000	127,263	670,286	955,061
	November	83,300	10,115	743,471	1,028,246
	December	65,200	10,453	798,218	1,082,993
1920	January	92,200	10,453	879,965	1,164,740
	February	69,000	9,778	939,187	1,223,962
	March	62,700	51,535	950,352	1,235,127
	April	75,000	73,792	951,560	1,236,335
	May	214,000	214,767	950,793	1,235,568
	June	249,000	229,219	970,574	1,255,349

* Denotes months in which there is a full reservoir and natural flow greater than the demand.

The combined demands in the foregoing table include the gross irrigation requirement for the Quincy Valley lands, and the supply for the new power plant near Dryden. Excess capacity in the reservoir would be provided sufficient in each case to provide for evaporation loss and the extra water which may be required for the Wenatchee canals. It was assumed that the reservoir would fill during the period of several years before the project reaches full development.

Study of the figures shows several interesting facts. In each of eleven years of the sixteen recorded, the reservoir would fill and a small amount be wasted. In the critical year of 1915, 177 feet in depth of storage would have been exhausted at the end of the irrigating season. A storage reservoir 195 feet in depth would have retained to the end of October nearly one-third of the runoff of the preceding year. Either reservoir could not have overflowed again until January, 1918, when the greatest winter flood in the record occurred.

Had the flow of the years ending October 31st, 1906, 1911, or 1915 followed that which actually occurred in 1915, the smaller reservoir would have been emptied before the end of the irrigating season. With the larger reservoir, under the same conditions, there would have been ample water with the flow of 1906 or 1911, but a shortage of over 200,000 acre-feet had the 1915 flow repeated itself.

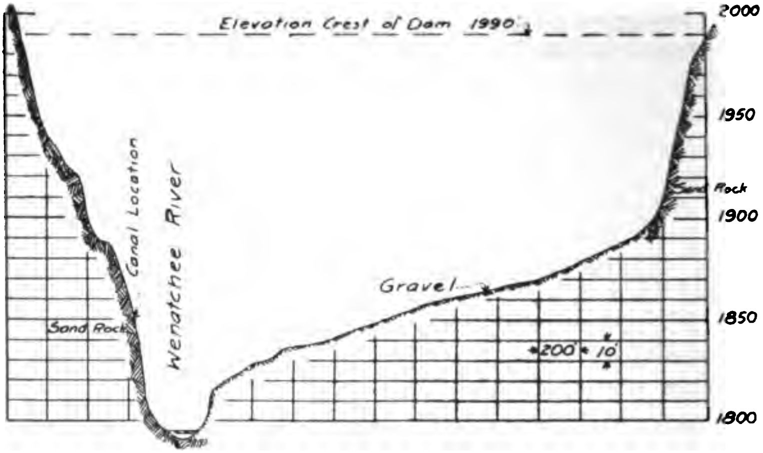
Examination of the stream below the outlet of Wenatchee Lake shows a practical place for a high dam about a mile below the mouth of Beaver Creek, near the east and west line between sections 13 and 24, T. 26 N., R. 17 E., W. M. At this place sandstone outcrops on both sides of the canyon and forms a barrier across across the river. Drilling or test-pitting will be necessary to determine whether bed rock extends under the sand and gravel flats on the west side of the stream. In the absence of such determination, it has been assumed that a satisfactory foundation will be found. No information, however, is available concerning the under-surface conditions and the lack of an adequate foundation may make this site impracticable.

Figure No. 37 shows the profile of the damsite and maximum section of the proposed dam. The quantities and estimated costs follow, both heights of dam being given for comparison:

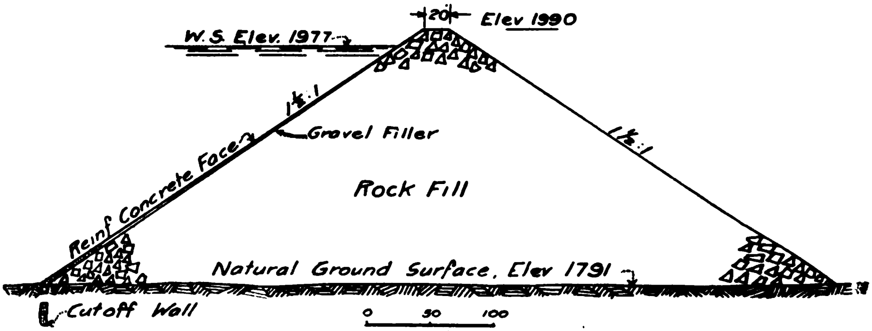
Table No. 63 — COST OF WENATCHEE RIVER DAM.

ITEM	Unit	Unit Cost	QUANTITIES		AMOUNTS	
			177-Foot Dam	195-Foot Dam	177-Foot Dam	195-Foot Dam
DAM—						
Overflow rights for reservoir	Acres	$10.00	12,875	14,400	$128,750	$144,000
Stripping excavation	Cu. Yd.	.30	100,746	115,082	30,224	34,525
Excavation for cut-off wall.	Cu. Yd.	1.50	15,371	15,371	23,057	23,057
Concrete in cut-off wall.....	Cu. Yd.	15.00	9,222	9,222	138,330	138,330
Rock fill	Cu. Yd.	.90	3,666,175	4,639,053	3,299,558	4,175,148
Preparation for facing......	Sq. Yd.	.30	84,057	96,176	25,217	28,853
Concrete facing	Cu. Yd.	18.00	39,305	48,295	707,490	869,310
RESERVOIR OUTLET—						
Excavation, solid rock......	Cu. Yd.	1.00	5,900	5,900	5,900	5,900
Concrete, heavy reinf........	Cu. Yd.	27.00	9,829	9,829	265,383	265,383
Cast iron discharge pipes...	Lb.	.06	600,000	600,000	36,000	36,000
Gates	....	....	....	....	170,500	170,500
Operating control	....	....	....	....	50,000	50,000
SPILLWAY—						
Excavation, solid rock......	Cu. Yd.	1.00	127,000	127,000	127,000	127,000
Concrete, heavy reinf.......	Cu. Yd.	27.00	52	52	1,404	1,404
Concrete, light reinf.........	Cu. Yd.	19.00	3,031	3,031	57,589	57,589
Engineering	....	....	....	....	151,990	188,810
					$5,218,392	$6,810,809
Contingencies	....	....	....	....	506,640	612,700
Totals..................	....	....	....	....	$5,725,032	$6,923,509

(5) *Conveyance of Water From Storage to Use.* A bench flume (Fig. No. 39), having a capacity of 4,720 second-feet, would convey the water for a short distance below the outlet from the reservoir and lead into a canal of the section shown in Fig. No. 40. The section of canal is varied (Fig. No. 41)



PROFILE



MAXIMUM SECTION

WENATCHEE RIVER DAM

WENATCHEE LAKE PROJECT

COLUMBIA BASIN SURVEY COMMISSION

STATE OF WASHINGTON

1920

FIG. 37.

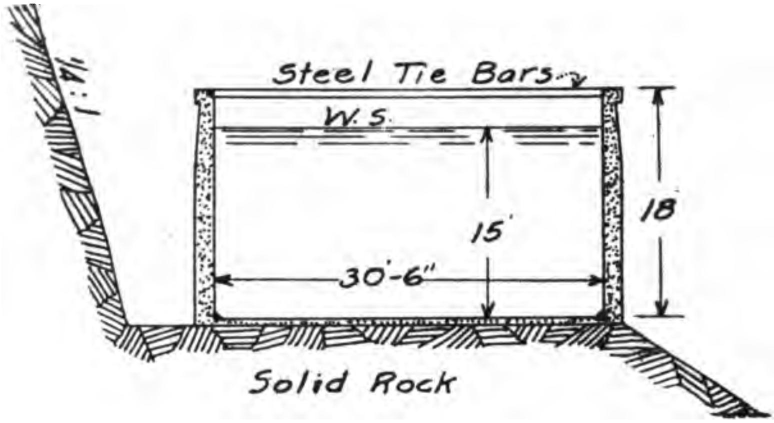


FIG. 39 — BENCH FLUME OF REINFORCED CONCRETE.

Width	30.5 ft.
Water depth	15 ft.
Wet perimeter	60.5 ft.
Section area	457.5 sq. ft.
Hydraulic radius	7.55 ft.
Kutter's "n"	0.014.
Slope	0.0007.
Fall	3.7 ft. per mile.
Velocity	10.4 ft. per second.
Quantity	4758 cubic feet per second.

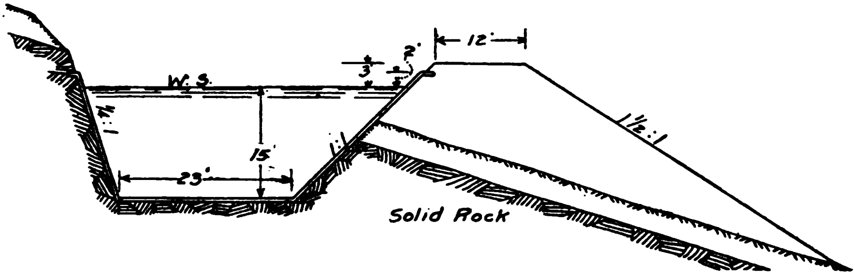


FIG. 40 — CANAL SECTION IN SOLID ROCK.

Bottom width	23 ft.
Water depth	15 ft.
Wet perimeter	59.4 ft.
Section area	485.6 sq. ft.
Hydraulic radius	8.18 ft.
Kutter's "n"	0.014.
Slope	0.00057.
Fall	3.0 ft. per mile.
Velocity	9.79 ft. per second.
Quantity	4745 cubic feet per second.

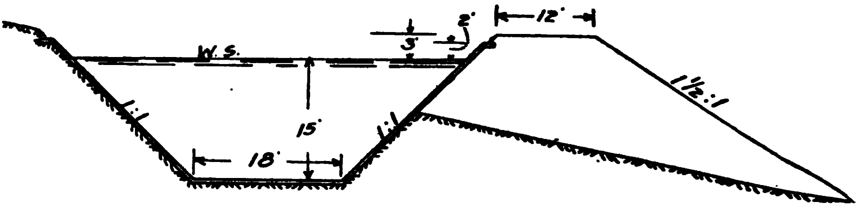


FIG. 41—CANAL SECTION IN EARTH.

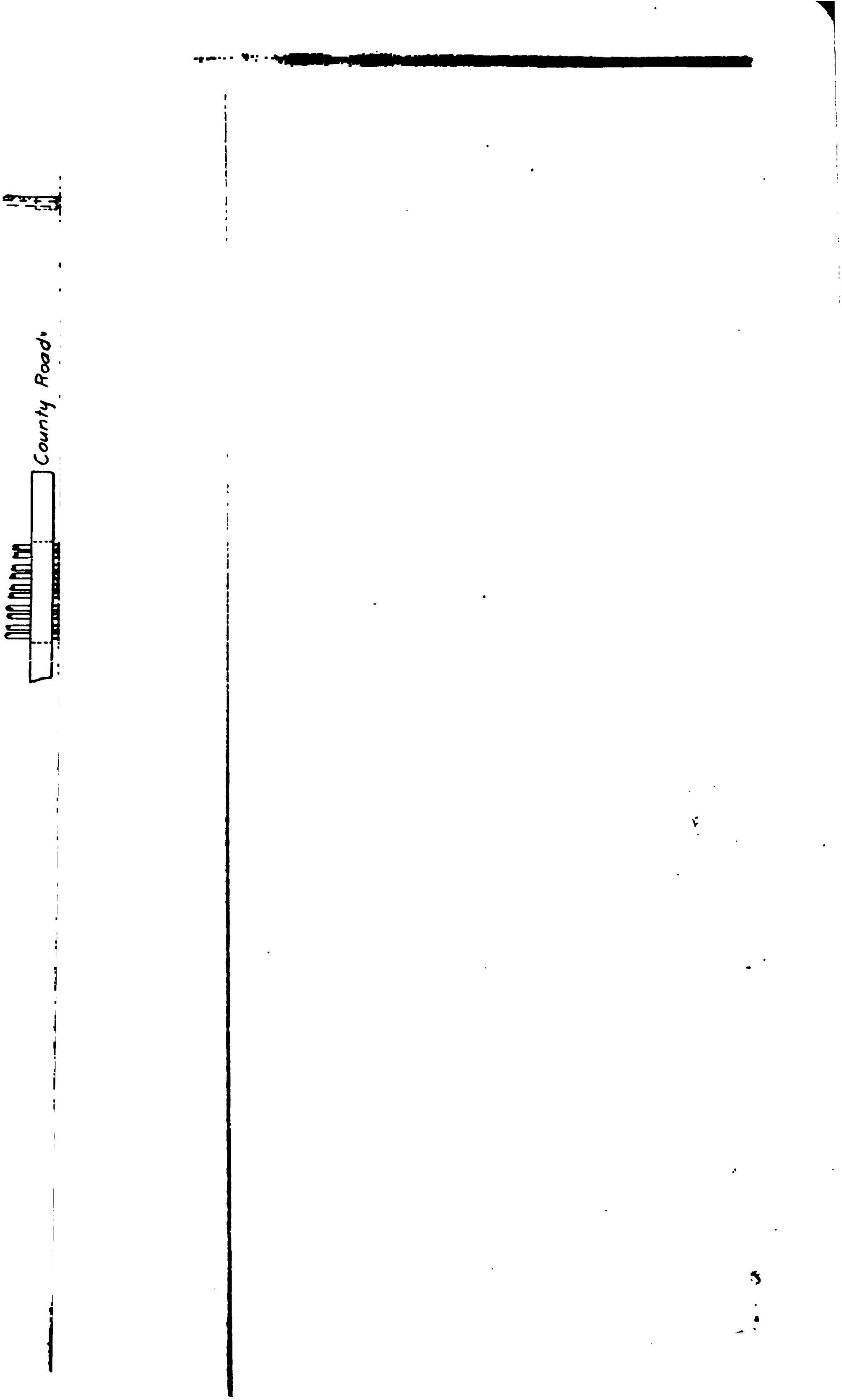
Bottom width	18 ft.
Water depth	15 ft.
Wet perimeter	60.6 ft.
Section area	495 sq. ft.
Hydraulic radius	8.16 ft.
Kutter's "n"	0.014.
Slope	0.00057.
Fall	3 ft. per mile.
Velocity	9.72 ft. per second.
Quantity	4815 cubic feet per second.

to meet the conditions imposed by the country traversed. Canal, tunnels (Fig. No. 42), bench flume and flume on fill have been planned at places where each type is best suited.

At Derby Canyon there is diverted 170 second-feet, through a 3.5 mile reinforced concrete conduit connecting with a penstock for the proposed power plant at Dryden. The Dryden plant would replace the plant near Leavenworth, saving an additional 355 second-feet for irrigation. The additional acreage which can be irrigated by this saving adds a value and annual income to the project greater than the capital cost and fixed charges caused by the installation of the new Dryden power plant. The new plant, due to the storage in the Wenatchee Lake reservoir, would have a more reliable water supply than the existing plant.

The canal leaving Derby Canyon would be reduced to 4,550 second-feet capacity. Above Sunnyslope a lateral would divert 22 second-feet of water for 2,000 acres, and the remaining 4,517 second-feet would be carried through to the Columbia River.

A high steel bridge was designed for the Columbia River crossing to carry an inverted siphon consisting of ten steel pipes. The alternate proposals to tunnel under the river or cross by pipes laid on the river bottom were studied. These proposals were rejected because of the unknown factors to be encountered beneath the channel and the much higher cost even under favorable conditions. Fig. No. 43 illustrates the general design of the proposed structure.


County Road

To supply valley lands along the East Wenatchee slope and in Moses Coulee, 222 second-feet would be required. At Rock Island Coulee, Moses Coulee, and Willow Spring Canyon, steel pipe inverted siphons are planned. None of these present as serious difficulty as the Columbia River crossing. On the canal east of the Columbia River several tunnels would be necessary.

The same considerations apply to the main canal from Wenatchee Lake to Quincy as governed in designing the supply canal from Albany Falls to Hillcrest. Consequently a deep section of concrete-lined canal and concrete-lined tunnels have been selected. Control gates, turnouts, drainage culverts, spillways, etc., have been designed similar to those under the Pend Oreille supply.

The distribution system south and east of Quincy is practically the same as that planned for the Pend Oreille supply.

(6) *Summary of Estimated Costs.* The same general considerations stated in connection with the estimates on the Pend Oreille supply apply to the cost of structures on the Wenatchee Lake project. Some variations in unit prices will be noted. Experience on the existing Wenatchee canals shows that the sandstone in that district can be drilled and blasted somewhat cheaper than can the basalt or granite, the respective excavating costs in canals being placed at $1.00 and $1.20 per cubic yard, and in tunnels at $5.20 and $6.70 per cubic yard. At all of the tunnels, excepting the Quincy and the Low Gap, materials for concrete lining must be hauled some distance from the railroad, over steep mountain roads, making the lining cost $16.50 per cubic yard. Under more favorable conditions, the lining is figured at $15.00 per cubic yard.

Tables numbered 64 to 70 recapitulate the dimensions, quantities and estimated costs of the principal structures on the supply and distribution systems from Wenatchee Lake.

Table No. 64 — COST OF CANALS AND FLUMES.

ITEM	Unit	Unit Cost	CANALS		BENCH FLUMES		ELEVATED FLUMES	
			Quantity	Amount	Quantity	Amount	Quantity	Amount
Right of way	Acre	$30.00	1,368	$41,040				
Right of way	Acre	10.00	452	4,520	67	$670	1	$10
Earth excavation	Cu. Yd.	0.25			174,964	43,741	18,785	4,695
Earth excavation	Cu. Yd.	0.20	5,604,615	1,120,923				
Loose rock	Cu. Yd.	0.60	984,136	590,483	70,600	42,360	2,820	1,692
Solid rock, sandstone	Cu. Yd.	1.00	104,924	104,924	315,116	315,116		
Solid rock, basalt and granite	Cu. Yd.	1.20	313,698	376,437	55,350	66,420		
Concrete lining	Cu. Yd.	16.00	526,214	8,419,424				
Reinforcing steel	Pound	0.06	7,733,385	464,005				
Reinforced concrete	Cu. Yd.	25.00					15,813	395,325
Reinforced concrete	Cu. Yd.	23.50			67,466	1,585,451		
Structural steel	Ton	120.00			861.19	103,343		
Engineering				256,825		64,715		16,020
Contingencies				1,084,317		107,850		20,090
Totals				$12,462,898		$2,329,666		$437,832

Table No. 65 — CANAL AND FLUME QUANTITIES.

ITEM	LOCATION	Length in Feet	Slope in Feet per 1,000	Velocity in Feet per Second	Capacity in Second-Feet		Excavation Cu. Yds.	Concrete Lining Cu. Yds.	Cost
					From	To			
Main Canal......	Wenatchee Dam to Quincy Flats.....	99,978	0.57	9.5 to 9.8	4,815	4,285	2,966,333	169,056	$4,742,846
Distributing Canals.	Quincy Flats to end of lines, 100 second-feet capacity and larger....	854,858	0.19 to 5.59	2.5 to 11.8	2,150	100	4,031,000	357,158	7,720,052
		954,836					6,997,333	526,214	$12,462,898
								Reinforced Concrete Cu. Yds.	
Bench Flume....	On Main Canal......................	24,519	0.70	10.1 to 10.4	4,758	4,340	616,030	67,466	$2,329,666
Elevated Flumes	On Main Canal......................	8,400	0.70	10.25	4,536	4,536	21,600	15,813	437,832
	Totals......................	....	....	....	....	....	7,634,963	....	$15,230,396

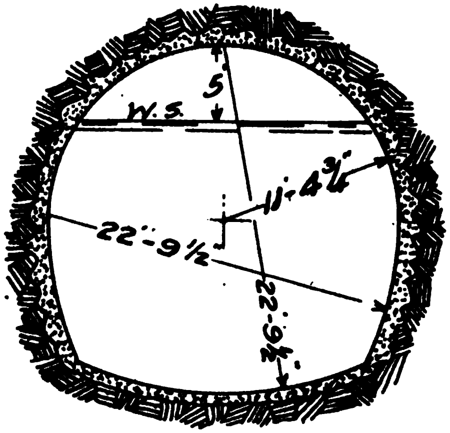


FIG. 42 — TUNNEL SECTION.

Diameter	22 ft. 9½ in.
Water depth	17 ft. 9½ in.
Water area	363 sq. ft.
Hydraulic radius	6.97 ft.
Kutter's "n"	0.015.
Slope	0.001405.
Fall	7.42 ft. per mile.
Velocity	13.0 ft. per second.
Quantity	4720 cubic feet per second.
Excavation	18.1 cubic yards per linear foot.
Concrete lining	2.94 cubic yards per linear foot,
Concrete lining	8 inches thick on bottom.
Concrete lining	13 inches thick on sides and arch.

Table No. 66 — COST OF TUNNELS.

LOCATION	RIGHT OF WAY			EXCAVATION			LINING		Engineering	Contingencies	Totals
	Acres	Unit Cost	Amount	Cu. Yds.	Unit Cost	Amount	Cu. Yd.	Amount of $16.50 per Cu. Yd.			
Chumstick	4	$10.00	$40	63,350	$5.20	$329,420	10,290	$169,785	$4,990	$49,920	$554,155
Eagle Creek	24	10.00	240	441,640	5.20	2,296,528	71,736	1,183,644	34,800	348,020	3,863,232
Derby Canyon	12	10.00	120	206,793	5.20	1,075,324	33,590	554,235	16,300	162,960	1,808,939
Nahahum Creek	32	10.00	320	563,421	5.20	2,929,789	91,887	1,516,136	44,460	444,590	4,935,296
Warm Springs	17	10.00	170	299,754	5.20	1,558,721	48,507	800,366	23,590	235,910	2,618,757
Sunnyslope	10	10.00	100	177,050	6.70	1,186,235	28,941	477,527	16,640	166,380	1,846,882
East Wenatchee	1	10.00	10	9,152	6.70	61,318	1,496	24,684	860	8,600	95,472
Rock Island	10	10.00	100	162,451	6.70	1,088,422	27,192	448,668	15,370	153,710	1,706,270
Moses Coulee No. 1	5	10.00	50	65,975	6.70	442,033	11,043	182,210	6,240	62,420	692,953
Moses Coulee No. 2	14	10.00	140	235,462	6.70	1,577,595	39,413	650,315	22,280	222,790	2,473,120
Willow Spring	7	10.00	70	100,800	6.70	675,360	16,821	277,547	9,530	95,290	1,057,797
Quincy	7	10.00	70	99,200	6.70	666,440	16,554	248,310*	9,150	91,480	1,015,450
Low Gap	4	30.00	120	76,050	7.76	590,148	14,670	220,050*	8,100	81,020	899,438
Totals	147	....	$1,550	2,501,098	....	$14,477,333	412,140	$6,753,477	$212,310	$2,123,090	$23,567,760

* At $15.00 per cubic yard.

Table No. 67 — Tunnel Quantities.

(All Single Bore.)

NAME	FORMATION	Length in Feet	Diameter Ft. In.	Slope in Feet per 1,000	Cu. Yds. Excavation per Lin. Ft.	Cu. Yds. Concrete Lining per Lin. Ft.	Capacity Sec.-Ft.	Average Cost per Lin. Ft.	Total Cost
Chumstick	Sandstone	3,500	22′ 8″	1.405	18.1	2.94	4,720	$158.33	$554,155
Eagle Creek	Sandstone	24,400	22′ 8″	1.405	18.1	2.94	4,720	158.33	3,863,232
Derby Canyon	Sandstone	11,425	22′ 8″	1.405	18.1	2.94	4,720	158.33	1,808,939
Nahahum Creek	Sandstone	32,700	22′ 2″	1.48	17.23	2.81	4,539	150.93	4,935,295
Warm Springs	Sandstone	17,080	22′ 4″	1.405	17.55	2.84	4,539	153.32	2,618,757
Sunnyslope	Granite	10,640	21′ 8″	1.67	16.64	2.72	4,539	173.58	1,846,882
East Wenatchee	Basalt	550	21′ 8″	1.67	16.64	2.72	4,517	173.58	95,472
Rock Island	Basalt	9,997	21′ 6″	1.67	16.25	2.72	4,384	170.68	1,706,270
Moses Coulee No. 1	Basalt	4,060	21′ 6″	1.67	16.25	2.72	4,384	170.68	692,953
Moses Coulee No. 2	Basalt	14,490	21′ 6″	1.67	16.25	2.72	4,384	170.68	2,473,120
Willow Spring	Basalt	6,800	21′ 4″	1.67	16.00	2.67	4,295	167.91	1,057,797
Quincy	Basalt	6,200	21′ 4″	1.67	16.00	2.67	4,295	163.77	1,015,450
Low Gap	Basalt	9,000	15′ 8″	0.757	8.45	1.63	1,341	99.94	899,438
Total	....	....	....	....	....	....	....	....	$23,567,760

Table No. 68—COST OF INVERTED SIPHONS.

LOCATION	RIGHT OF WAY			SIPHON STEEL		EXCAVATION FOR PIERS		CONCRETE IN PIERS		REINFORCING STEEL IN PIERS	
	Acres	Unit Cost	Amount	Pounds	Amount at 7c per Pound	Cu. Yds.	Amount at $1.00 per Cu. Yd.	Cu. Yds.	Amount at $15.00 per Cu. Yd.	Pounds	Amount at 6c per Pound
Columbia River	19	$10.00	$190	85,000,000	$5,950,000	28,025	$28,025	38,343	$575,145	....	....
Rock Island	14	10.00	140	33,041,864	2,312,930	18,400	18,400	12,383	185,745	202,400	$12,144
Moses Coulee	14	10.00	140	54,002,742	3,780,192	20,833	20,833	15,662	234,930	276,100	16,566
Willow Spring	2	10.00	20	1,482,240	103,757	1,620	1,620	1,631	24,465	19,800	1,188
Great Northern	......	....	....	1,976,636	138,365	3,878	3,878	1,310	19,650	34,320	2,059
Potholes	9	30.00	270	31,199,720	2,183,980	28,956	28,956	25,146	377,190	675,640	40,538
Frenchman	10	30.00	300	14,714,610	1,030,023	16,146	16,146	14,053	210,795	164,450	9,867
Babcock	4	30.00	120	4,230,000	296,100	3,960	3,960	4,716	70,740	63,000	3,780
Lateral "N6"	4	30.00	120	3,335,500	233,485	2,038	2,446†	1,650	24,750	43,300	2,598
Totals	......	....	$1,300	228,983,312	$16,028,832	123,856	$124,264	114,894	$1,723,410	1,479,010	$88,740

† At $1.20 per cubic yard.

Table No. 68 — COST OF INVERTED SIPHONS — Concluded.

LOCATION	VALVES		Transitions	SPECIAL ITEMS		Railroad Maintenance and Spurs	Engineering	Contingencies	Totals
	No.	Amount at $500 Each		Amount					
Columbia River	30	$15,000	$211,615		$3,036,238*	$1,500	$178,500	$159,700	$10,155,918
Rock Island	8	4,000	99,650	HC	1,500	....	69,390	31,590	2,735,489
Moses Coulee	6	3,000	63,230	RE	5,070				
				RC	18,075	....	113,410	35,870	4,291,816
Willow Spring	2	1,000	63,230	HC	9,500	....	3,110	9,360	217,250
Great Northern	1	500	....	HR	27,540				
				LR	7,600	5,000	4,150	6,070	214,812
Potholes	3	1,500	....	HR	13,500				
				LR	10,260	70,000	65,520	44,670	2,836,384
Frenchman	1	500	....	....	....	35,000	30,900	23,680	1,357,211
Babcock	1	500	....	T	7,000	....	8,880	7,850	396,980
	7	3,500	....	F	3,000				
				HR	891				
Lateral "N6"				LR	1,216	5,000	7,000	3,490	287,496
Totals	59	$29,500	$437,725		$3,141,390	$116,500	$480,860	$322,280	$22,494,801

HC—Highway crossing.
UP—Unwatering and excavation four high piers
PE—Excavation for anchor piers.
PS—Structural steel for anchor piers.
GE—Grading right of way—Solid rock excavation.
HR—Concrete, heavy reinforcement.
LR—Concrete, light reinforcement.
BS—Structural steel bridge.
OP—Four-foot reinforced concrete pipe.
RE—Excavation for railroad crossing.
RC—Concrete in railroad crossing.
T—Transportation.
F—Preparation of footings.

*UP	$180,000
PE	6,256
GE	39,879
HR	18,603
LR	537,400
PS	1,080
BS	2,234,520
HC	9,500
OP	9,000
	$3,036,238

Table No. 69 — INVERTED SIPHON QUANTITIES.

LOCATION	Length in Feet	Maximum Head in Feet	No. of Pipes	Diameter of Pipes	Veloc. in Feet per Second	Capacity in Second-Feet	Weight of Steel in Pounds	Cost
Columbia River	8,299	1,000	10	6′ 0″	15.9	4,500	85,000,000	$10,155,913
Rock Island Coulee	4,146	755	8	8′ 0″	10.9	4,384	33,041,364	2,735,489
Moses Coulee	6,448	670	6	9′ 6″	10.1	4,396	54,002,742	4,291,316
Willow Spring	920	100	2	16′ 0″	11.1	4,462	1,482,240	217,250
Great Northern	1,621	175	1	16′ 6″	10.1	2,160	1,976,636	214,812
Potholes	25,400	232	1	16′ 3″	10.0	2,074	31,199,720	2,836,384
Frenchman	14,950	242	1	15′ 6″	9.6	1,812	14,714,610	1,357,211
Babcock	9,000	50	1	10′ 0″	7.1	558	4,230,000	398,930
Lateral "N6"	9,530	100	1	9′ 0″	13.8	876	3,335,500	287,496
Totals	80,314	....	......	....	....	....	228,983,312	$22,494,801

Table No. 70 — RECAPITULATION OF COSTS.

ITEM	Total Cost
Wenatchee River Dam	$5,725,032
Bench Flumes, Wenatchee River Dam to Quincy Flats	2,329,666
Canal, Wenatchee River Dam to Quincy Flats	4,742,846
Chumstick Tunnel	554,155
Eagle Creek Tunnel	3,863,282
Derby Canyon Tunnel	1,808,939
Nahahum Creek Tunnel	4,935,295
Dryden PowerPlant	696,218
Warm Springs Tunnel	2,618,757
Sunnyslope Tunnel	1,846,882
Columbia River Inverted Siphon	10,155,913
East Wenatchee Tunnel	95,472
Trestle Flumes, Columbia River to Quincy Flats	437,832
Rock Island Tunnel	1,706,270
Rock Island Inverted Siphon	2,735,489
No. 1 Tunnel, Moses Coulee	692,953
No. 2 Tunnel, Moses Coulee	2,473,120
Moses Coulee Inverted Siphon	4,291,316
Willow Spring Tunnel	1,057,797
Willow Spring Inverted Siphon	217,250
Quincy Tunnel	1,015,450
Canal, Mains and all laterals, Quincy Flats to end of line	7,720,052
Great Northern Inverted Siphon	214,812
Potholes Inverted Siphon	2,836,384
Frenchman Springs Inverted Siphon	1,357,211
Low Gap Tunnel	899,438
Babcock Inverted Siphon	398,930
Inverted Siphon, Lateral "N6"	287,496
Chute, Lateral "N7"	25,087
Distribution below 100 second-feet capacity	6,150,000
Spillways and Wasteways on Main Supply Canal	95,410
Spillways and Wasteways on Distribution System	120,000
Lateral Headgates	143,200
Road Crossings	71,742
Drainage Culverts	53,810
Telephone Lines	146,400
Fences	189,900
General engineering, administration, and legal expense, preceding construction	287,000
Administration, legal, and general expense, during construction	718,000
General incidentals, miscellaneous items, including patrol houses	200,000
Total	$75,914,756
Cost per acre, irrigating 410,000 acres	$185.15

(7) *Comparison With Pend Oreille Supply.* What is designated as the Quincy area under the Pend Oreille supply includes 425,000 acres. Under the Wenatchee supply there would be 410,000 acres, of which 23,000 acres are below the supply canal before reaching Quincy.

If the Wenatchee supply and the Pend Oreille Plan V (page 47) were both developed, there would be left arid 38,000 acres between Black Rock Coulee and Soap Lake, more than offsetting the 23,000 acres gained along the Wenatchee line.

The Pend Oreille maximum development (Plan I, page 43), costing $300,475,678, would water 1,753,000 acres. The Wenatchee project and Pend Oreille Plan V, costing $304,462,917, would water 1,738,000 acres. The fact that either the Wenatchee or Pend Oreille supply for Quincy District may be developed makes the Wenatchee rights a valuable asset for the Quincy area which should be conserved until that area receives water from one or the other source. The Quincy Valley Irrigation District should exert every legitimate means to retain its present rights and withdrawals in connection with the water and shore lands of Wenatchee Lake, until it has been definitely determined which source of water supply shall be developed for their lands.

The gravity system from Wenatchee Lake was designed to reclaim all the land for which there would be sufficient water. The supply canal would reach the head of Babcock Main about 75 feet higher than would the Pend Oreille supply. This adds 22,000 acres to the irrigable area over that of the Pend Oreille on the west side of the district, but owing to the greater pressure heads at The Potholes and Frenchman Springs inverted siphons, their costs would be increased and the cost of distribution per acre of the area would be higher. There is a possibility of slightly reducing the distribution cost by lowering the canal grade and pumping to all or a part of the 22,000 acres above a lower canal. It is also possible that a reduction in the total area to be reclaimed might decrease the cost per acre a small amount. Many items of cost would remain practically the same regardless of the area, but the inverted siphons would be smaller and under lower heads, and a small reduction in the total cost might result.

As between the two sources of water, the Pend Oreille offers an ample supply at all times, with a great surplus every year, while the Wenatchee may at intervals require restriction of use to prevent an actual exhaustion of supply before the end of the irrigating season.

The extremely high pressures in the inverted siphons, especially at the Columbia River crossing, create a more serious question than the inverted siphons along the Pend Oreille line.

The Pend Oreille supply canal will be easy to maintain and operate. The upper reaches of the Wenatchee supply canal would fill every winter with snow and ice with possible damage to lining and gates and the need of careful repair and cleaning out every spring. The lateness of spring in the high mountains in the Wenatchee watershed would frequently delay thawing of ice in the canals until late in April, after irrigation would be needed in the Quincy district. Many of the hillsides along the Wenatchee are covered with moving talus, offering an uncertain support for the canal or flume, and the accumulation of debris in the canal or against the flume. The Pend Oreille canal would have no such difficulties.

The discussion of the Wenatchee Lake water supply for the Quincy area is based on the assumption that favorable foundation conditions exist at the damsite. Should it be found that it is not practicable to construct a dam of sufficient height to create the necessary storage, the entire Wenatchee-Quincy project becomes infeasible.

APPENDIX J.

There have been prepared a large number of maps, diagrams and tables in addition to those published in this report. These are filed in the offices of the commission and may be consulted by any person interested in examining the original data. The index map (No. V, opposite page 42) shows the area covered by the several maps and within the rectangles are the filing numbers which identify the corresponding topographic maps, profiles, or special studies.

The field maps show the lines as surveyed, the relocated line as estimated, the topography and cultural features along each line, and profiles of the respective lines, with classification of materials to be encountered during excavation.

The plats showing soil surveys, ownership and flooded areas, either from backwater at reservoirs or by the wasteways discharge, are bound in one volume, arranged by township and range within each group.

The files also preserve a number of studies of water supply at various places under differing conditions of storage and demand, estimates of several types of dams, numerous alternative designs of structures, and an extensive collection of books and reports dealing with irrigation in the United States and abroad.

Appendix K.

SESSION LAWS, 1919.—CHAPTER 60.

(S. H. B. 3)

Columbia Basin Irrigation Project.

An Act providing for the survey of the Columbia Basin Irrigation Project, creating a commission therefor, defining its powers and duties, and making an appropriation and declaring that this act shall take effect immediately.

Be it enacted by the Legislature of the State of Washington:

Section 1. There is hereby created a commission, to be known as the "Columbia Basin Survey Commission," to consist of the state hydraulic engineer *ex-officio*, as chairman, and four members who shall be appointed by and removable at the pleasure of the Governor. Each commissioner shall serve as such without compensation but shall be allowed his actual necessary expenses incurred in the performance of his duties. The Governor shall appoint the members of said commission and the commission shall organize and select one of their number as secretary and enter upon the performance of their duties within thirty days after the taking effect of this act.

Sec. 2. It shall be the duty of said commission to make or cause to be made a survey of the Columbia Basin Irrigation Project and to prepare a compilation and report of the result of such survey and present the same to the proper department or departments of the federal government for consideration, and to recommend and urge the appropriation of funds for the carrying out of the project for the improvement of the Columbia River Basin by irrigation. The commission shall have the power to employ such persons as may be necessary to assist them in their work, and to expend such of the funds appropriated by this act as they may deem necessary for such purposes.

Sec. 3. For the purpose of carrying out the provisions of this act there is hereby appropriated out of the general fund the sum of one hundred thousand dollars ($100,000.00), or so much thereof as may be necessary.

Sec. 4. This act is necessary for the immediate preservation of the public peace, health and safety and the support of the state government and its existing public institutions and shall take effect immediately.

Passed the House February 11, 1919.
Passed the Senate February 19, 1919.
Approved by the Governor March 1, 1919.

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